Status Report on the Shortjaw Cisco (*Coregonus zenithicus*) in Central and Western Canada

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STATUS REPORT ON THE SHORTJAW CISCO (*COREGONUS ZENITHICUS*) IN CENTRAL AND WESTERN CANADA

by

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Abstract

Murray, L., and J. D. Reist. 2003. Status report on the shortjaw cisco (*Coregonus zenithicus*) in central and western Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2638: vii + 56 p.

An extensive literature review was undertaken to summarize current knowledge on the status of shortjaw cisco (*Coregonus zenithicus*) outside the Great Lakes. Information was obtained from journal articles, books, data reports, and personal communication with people familiar with the subject. A review of North American cisco systematics is included along with a discussion of shortjaw cisco taxonomy within and outside the Great Lakes. The literature review is summarized in lake-by-lake status reports giving information on: 1) the original description of *C. zenithicus*, 2) any further descriptions made, 3) conclusions on the current status of *C. zenithicus* in each lake, 4) distribution information of *C. zenithicus* and sympatric *C. artedi* including maps, and 5) potential limiting factors to *C. zenithicus* populations in each lake. The overall findings from this review reveal a lack of information about the status of *C. zenithicus* and ciscoes in general from western Canada.

Résumé

Murray, L., et J. D. Reist. 2003. Status report on the shortjaw cisco (*Coregonus zenithicus*) in central and western Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2638: vii + 56 p.

Nous avons effectué une revue approfondie de la littérature afin de résumer les connaissances actuelles sur l'état du cisco à mâchoires égales (*Coregonus zenithicus*) à l'extérieur des Grands Lacs. Nous avons obtenu de l'information dans des articles et rapports scientifiques, des livres et des communications personnelles entretenues avec des connaisseurs en la matière. Nous présentons une synthèse taxinomique des ciscos nord-américains et nous discutons de la taxinomie du cisco à mâchoires égales dans les Grands Lacs et à l'extérieur de ceux-ci. Nous résumons notre revue de la littérature dans des rapports de situation pour chaque lac qui présentent des informations sur les aspects suivants : 1) description initiale de *C. zenithicus*; 2) toutes les descriptions ultérieures; 3) conclusions sur l'état actuel de *C. zenithicus* dans chaque lac; 4) répartition de *C. zenithicus* et de *C. artedi*, une espèce sympatrique, avec cartes à l'appui; 5) facteurs limitants possibles pour la population de *C. zenithicus* de chaque lac. Cette revue a révélé un manque de connaissances sur l'état de *C. zenithicus* et des ciscos de l'Ouest canadien en général.

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INTRODUCTION

Shortjaw cisco (*Coregonus zenithicus* (Jordan and Evermann 1909)) are freshwater fishes of the family Salmonidae. They have typical trout-like bodies and most species of ciscoes occupy lacustrine environments where they feed in the water column on zooplankton. Shortjaw ciscoes are members of the subfamily Coregoninae, one of the most widely distributed and taxonomically perplexing groups of all Canadian freshwater fish. Shortjaw cisco were previously abundant in most of the Great Lakes but are now extirpated or threatened due to impacts from the "chub" cisco fishery, competition and predation by invading species, and environmental degradation. Beyond the Great Lakes, shortjaw cisco have been reported in approximately 20 lakes extending northwest to Great Slave Lake, however, information pertaining to their abundance, biology, and status is limited (Scott and Crossman 1973). Shortjaw ciscoes were listed as a threatened species by the Committee on the Status of Endangered Wildlife In Canada (COSEWIC) in 1987 (Houston 1988).

Shortjaw ciscoes were originally described from Lake Superior in 1909 by Jordan and Evermann. The type specimen was a large deep-water cisco with a long shallow snout and few, short gillrakers. Formerly abundant in most of the Great Lakes, shortjaw ciscoes are now considered to be extinct in all except Lake Superior, where they are threatened.

Outside of the Great Lakes shortjaw ciscoes have received little attention with the exception of a few studies (Dymond 1943, Keleher 1950, Clarke 1973, Steinhilber 2000). The purpose of this report is to summarize available information on shortjaw ciscoes beyond the Great Lakes region. Various sources were used to determine the reported distribution, initial identification, further descriptions, biological information, and potential threats for putative shortjaw cisco populations.

SYSTEMATICS OF COREGONINAE

Ciscoes are members of the Salmonidae family which includes the trouts, salmons, and graylings. Along with whitefish and the inconnu, ciscoes comprise the subfamily Coregoninae, which differ from trout and salmon by having larger scales and toothless maxillae. Within the subfamily there are three genera: *Prosopium*, the round whitefishes; *Stenodus*, the inconnu; and *Coregonus*, the lake whitefishes and ciscoes (Scott and Crossman 1973). Ciscoes have been considered separate from the whitefishes in the past on the basis of their many long gillrakers, antrose premaxillae, and maxillae ending beneath the pupil (Clarke 1973). Whitefish were placed in the genus *Coregonus* by Linnaeus (1758). In 1818 Le Sueur first described North American ciscoes and placed them with the whitefish in the genus *Coregonus*. From 1850 to 1911 North American ciscoes were considered distinct from the whitefishes and were placed under the genus *Argyrosomus*. In 1911 it was realized that *Argyrosomus* was already in use for a sciaenid so it was replaced by *Leucichthys*, first used in 1874 by Dybowski for coregonids with terminal mouths. Ciscoes and lake whitefish (*Coregonus clupeaformis* (Mitchell 1818)) are currently grouped together in the genus *Coregonus*, however, studies have found this arrangement to be polyphyletic (Bodaly *et al.* 1991, Bernatchez *et al.*1991, Reist *et al.* 1998).

Whitefishes and ciscoes are characterized by having a double nostril flap, no basiobranchial plate, and young lacking parr marks. Whitefish usually differ from ciscoes

by having relatively few and short gillrakers, and small, subterminal mouths (Scott and Crossman 1973). There is evidence suggesting the existence of two or three distinct clades within the cisco group. The North American species have been considered as one group, this includes all endemic North American species, as well as Arctic ciscoes, *C. autumnalis* (Pallas 1776), and Bering ciscoes, *C. laurettae* (Bean 1882), or as two groups, the Great Lakes species and the northwestern species. The other group consists of all Eurasian forms and the least cisco, *C. sardinella* (Valenciennes 1848) (Smith and Todd 1992, Reist *et al.* 1998).

GREAT LAKES CISCOES

Shortjaw ciscoes are members of a taxonomically complicated group of closely related cisco forms. The extreme of their radiation was found in the Great Lakes region of North America (Todd and Smith 1992). This group included five deepwater species endemic to the Great Lakes including Lake Nipigon [deepwater cisco (*C. johannae* (Wagner 1910)), longjaw cisco (*C. alpenae* (Koelz 1924), shortnose cisco (*C. reighardi* (Koelz 1924), bloaters (*C. hoyi* (Gill 1872), and kiyi (*C. kiyi* (Koelz 1924)] (Scott and Crossman 1973, Todd and Smith 1992). Shortjaw ciscoes and blackfin ciscoes (*C. nigripinnis* (Gill 1872)) were also abundant in the deep waters of the Great Lakes as well as being reported from various lakes outside the region, however, the identification of blackfin ciscoes beyond the Great Lakes is uncertain (Scott and Crossman 1973, Clarke 1973). The seven species mentioned above were collectively referred to as "chubs" and supported a large commercial fishery until the 1950's when stocks crashed. *C. hoyi* is now the only "chub" species believed to be abundant in the Great Lakes, however, it has been extirpated from Lake Ontario. *C. johannae* and *C. reighardi* are believed to be extinct while *C. kiyi* has been extirpated from Lakes Ontario, Huron, and Michigan but remains abundant in Lake Superior. *C. nigripinnis* has been extirpated from lakes Huron and Michigan but remains abundant in Lake Nipigon. *C. zenithicus* is believed to be extirpated from all the Great Lakes with the exception of Lake Ontario where it was never reported, Lake Superior where it is rare, and Lake Nipigon where it remains abundant (Todd and Smith 1992). Todd *et al.* (1981) suggested *C. alpenae* to be synonymous with *C. zenithicus* based on findings that the major difference between the two species was the larger size of *C. alpenae*, beyond this the two were morphologically similar.

C. artedi Le Sueur 1818 (referred to as lake herring in the Great Lakes and lake cisco or tullibee in most inland locations) is also part of the cisco complex found in the Great Lakes, however, it was not part of the deepwater "chub" fishery (Scott and Crossman 1973). Lake herring are considered rare in Lake Huron, threatened in lakes Ontario, Erie, and Michigan, and abundant in lakes Superior and Nipigon (Todd and Smith 1992). Lake herring are the most widespread cisco species in North America extending northwest to Great Bear Lake (Scott and Crossman 1973). Prior to human perturbation, the Great Lakes ciscoes displayed the greatest amount of cisco diversity in the world. These forms likely represented an adaptive radiation to the diverse ecosystems present in the large lakes which developed in post-glacial times (Todd and Smith 1992). Prior to human perturbation taxonomic work was limited, thus we have little idea of the diversity that was originally present, but numerous forms were described (Koelz 1929).

CISCO RADIATION AND EVOLUTION IN NORTH AMERICA

A commonly accepted theory about North American cisco evolution is that shortjaw ciscoes and lake herring were both original post-glacial colonizers of many North American lakes after surviving the Pleistocene glaciation in the Mississippi refugium and invading inland lakes (Clarke 1973, Bailey and Smith 1981, Smith and Todd 1984). Bailey and Smith (1981) felt differentiation between lake herring and shortjaw cisco most likely occurred sometime during the 70 000 years of the Wisconsinan glaciation or earlier, however, they did not rule out the possibility of them evolving post-glacially. Bailey and Smith (1981) also felt that the similarity displayed between ciscoes in Lake Nipigon and Lake Superior, once connected by proglacial lakes but now isolated by barrier falls, suggested that major cisco differentiation occurred earlier than 9000 years ago before present.

Morphological variation displayed within each species throughout their ranges most likely arose by allopatric and sympatric intralacustrine genetic differentiation and phenotypic plasticity (Steinhilber 2000). The cold-water habitat of proglacial lakes and rivers connecting the Mississippi/Missouri refugium with northwestern North America provided the cold-water adapted shortjaw cisco and lake herring with suitable dispersal routes in the late-Wisconsinan (McPhail and Lindsey 1970, Teller 1987). Glacial lakes Agassiz, Saskatchewan, and Edmonton as well as other smaller lakes and drainage channels would have provided a suitable opportunity for cold-water adapted fish such as ciscoes to extend their range as far north as the Mackenzie River (Steinhilber 2000). Approximately 30 species of fish believed to have originated from the Mississippi/Missouri refugium now inhabit the Hudson Bay and upper Mackenzie drainage basins (Lindsey and McPhail 1986, Rempel and Smith 1998). The reported distribution of shortjaw cisco in inland lakes is more sporadic than that of lake herring, suggesting that lake herring were the more successful competitor when suitable habitat was at a premium. Shortjaw cisco populations, with the exception of Barrow Lake, are usually found in deeper water than sympatric lake herring (Scott and Crossman 1973). In shallower northern lakes where both species may have originally invaded it is likely that lake herring were the stronger competitor causing extirpation or introgression of shortjaw cisco forms. In deeper lakes with suitable habitat for each species, both were able to thrive and populate the water bodies.

Another theory that has come to the forefront recently is that a single taxon radiated out from the Great Lakes through post-glacial lakes and diverged into different morphotypes within each water body through parallel evolution. In this case the shortjaw cisco-like forms found outside of the Great Lakes would be more closely related to the sympatric lake herring from which they were originally derived. If this is the case then Great Lakes shortjaw ciscoes represent a valid species and inland shortjaw cisco populations represent superficially morphologically similar forms derived from lake herring. The characters used to differentiate sympatric cisco forms are similar to those found to differ within other fish species with benthic and pelagic fish forms. These characters may be influenced more by the environment (i.e. feeding, swimming) than by genetics (Robinson and Parsons 2002). Work with microsatellite loci has provided preliminary support for this theory, however, further work with a greater number of reported shortjaw cisco populations would help clarify their taxonomy (Turgeon and Bernatchez 2002).

SHORTJAW CISCO TAXONOMY

Shortjaw cisco identification is uncertain due to the amount of phenotypic plasticity they display over their geographic range and their morphological similarity to sympatric lake herring (Koelz 1929, Dymond 1943, Scott and Crossman 1973, Clarke 1973, Todd and Steinhilber 2002, Steinhilber *et al.* 2002). The primary means of shortjaw cisco identification has been based on gillraker counts. Shortjaw ciscoes usually have less than 40 short, widely spaced gillrakers while lake herring commonly have 40 or more closely packed, long gillrakers (Todd & Smith 1980). Although gillraker counts are genetically based, they have been shown to be variable in Coregonines under differing environmental conditions in laboratory reared and natural populations (Lindsey 1981, Todd *et al.* 1981).

The use of a single character for species identification is often unreliable especially for morphologically plastic fish such as cisco (Steinhilber *et al.* 2002). Table 1 lists some characters that have been used for distinguishing between shortjaw ciscoes and lake herring, however, overlap of values is common, especially between water bodies. Shortjaw ciscoes are elliptical in shape like most other ciscoes and are laterally compressed with large, smooth, silvery scales. They are generally light in dorsal colouration ranging from tan to light brown and white ventrally. The lower jaw is usually even with or shorter than the upper jaw and the premaxillaries usually make a distinct angle from the horizontal axis of the head (Scott and Crossman 1973, Clarke 1973, Todd and Smith 1980). These characters are not always diagnostic for species identification.

Typical of coregonine fishes, convergence in the characters used to differentiate taxa and identify species is common. Thus, the distinctness and specific identity of many cisco taxa is in doubt. Shortjaw ciscoes represent a cisco form whose validity as a distinct species has been questioned (Steinhilber and Rhude 2001, Turgeon and Bernatchez 2002). Although some consistent morphological differences have been found between populations of putative shortjaw cisco and lake herring (Clarke 1973, Todd and Smith 1980), genetic studies conducted to date have failed to find any significant differences between their DNA (Reed *et al.* 1998, Turgeon *et al.* 1999, Steinhilber *et al.* 2002). It is possible that the time since the two species diverged has not been enough for genetic differences to be evident (Bailey and Smith 1981, Smith and Todd 1984, Reed *et al.*1998). It is also possible that genetic differences cannot be found because a single taxon, lake herring, may have radiated out from the Great Lakes. Through parallel evolution a deepwater feeding low gillraker morphotype was produced where suitable habitat was available. The low gillraker morphotypes differ morphologically from the sympatric lake herring, however, genetically they show a high degree of relatedness (Turgeon and Burnatchez 2002).

THREATS AND LIMITING FACTORS

Three classes of anthropogenic impacts can be identified as contributing to the decline of coregonine populations generally and shortjaw cisco populations in particular in the Great Lakes. These are commercial overfishing, habitat degradation, and introduction of exotic species. Within each class, there are usually several factors that act individually as well as cumulatively (i.e., synergistically) to affect key elements of the life history of shortjaw cisco.

Commercial exploitation in the 19th and 20th centuries focused upon larger ciscoes in the Great Lakes (e.g., deepwater and blackfin), that were driven to commercial extinction by the 1950's. As large ciscoes declined, mesh size of gill nets was decreased to maintain the fisheries (Smith 1964), and medium-sized fish such as shortjaw cisco became the commercial fishery target. Coincident with fishery exploitation, the aquatic habitat in the Great Lakes was being impacted. This included degradation of water quality (e.g., increased sedimentation due to logging, urbanization, etc.), and contamination (e.g., addition of noxious chemicals). Ciscoes tend to be cold water species of fish occupying deeper areas of lakes in the summer, thus thermal shifts in habitat (e.g., thermal effluent from power generating stations) also likely contributed to declines. Such habitat impacts tend to be ubiquitous, low-level and chronic thus the direct evidence for these as factors in the decline is generally poor. However, these almost certainly contributed to coregonine declines in the Great Lakes.

The connection of the Great Lakes to the St. Lawrence River via the system of locks of the St. Lawrence Seaway and the subsequent traffic of commercial ships has resulted in the invasion of the Great Lakes basin by exotic (i.e., non-indigenous) species. This has occurred through natural invasion as barriers to upstream movements were removed (e.g., sea lamprey, *Petromyzon marinus* (Linnaeus 1758)) and through artificial introduction via the release of bilge water in the Great Lakes (e.g., zebra mussel, *Dreissena polymorpha* (Pallas 1771)). Exotics appear to have affected cisco populations in a number of ways. Sea lamprey decimated lake trout, *Salvelinus namaycush* (Walbaum 1792), populations in the lakes in the 1940-1950's and then appear to have switched to preying on the medium-sized ciscoes present in the lakes (i.e., by this time, shortjaw cisco were among the larger forms of cisco still extant). Simultaneously, as a consequence of reduced predation by fewer lake trout, populations of smaller cisco species (e.g., bloater) increased in abundance (Smith 1964). These smaller species compete with shortjaw cisco for the same zooplankton resources. Also during this time, two other fish species (alewives, *Alosa pseudoharengus* (Wilson 1811) and rainbow smelt, *Osmerus mordax* (Mitchill 1814)) were introduced increasing such competition further. These exotic species have had significant overall impacts on the native cisco populations in this area.

The individual effects of each class of anthropogenic impacts on shortjaw cisco and other endemic ciscoes of the Great Lakes have been substantial. Within each class and between classes of impacts, individual impacts have likely also acted synergistically to result in a greater total impact on particular populations of ciscoes. These have culminated in severe reductions in population abundance of shortjaw cisco as well as disruption of habitat cues used in critical life history activities such as reproduction. Furthermore, as populations become rare another factor comes into play to exacerbate the situation. In fish such as ciscoes, low abundance of one species in comparison to closely related congeners and disruption of normal life history activities often leads to increased hybridization among the species. This, in turn, leads to introgression of foreign genotypes into species. In the case of species that are rare, such introgression ultimately may result in the genetic swamping of the original species, thus effectively altering the original genetic makeup of the species irrevocably. Over time, such swamping may provide the final factor in extirpating that species from the area. This appears to have been the cause of shortjaw cisco extirpation in most of the Great Lakes (Todd and Stedman 1989).

Putative populations of shortjaw cisco outside of the Great Lakes basin experience similar threats as described above. For example, exploitation of coregonines either as directed fisheries for ciscoes or as fisheries for other species in which cisco are captured as by-catch likely occurs in most of the large lakes where shortjaw cisco are thought to occur. Habitat degradation in such areas is likely occurring but no specific understanding of this is currently available. Also, in some cases invasion by exotic species is occurring (e.g., rainbow smelt are established in Lake Winnipeg). Although likely not as severe in these areas as they have been in the Great Lakes, these impacts almost certainly affect shortjaw cisco in these areas. Our ability to assess these impacts and to properly assess the current status of shortjaw cisco populations in lakes other than the Great Lakes is compromised by the taxonomic issue of whether these low gillraker forms represent actual populations of shortjaw cisco. The status question and taxonomic problem are key issues that require resolution as part of any plan to manage this threatened species.

DISTRIBUTION OF SHORTJAW CISCO IN CANADA

Originally present in all the Great Lakes except Lake Ontario, shortjaw cisco are now extirpated from all except Lake Superior where they are rare and Lake Nipigon where they remain abundant (Todd and Smith 1992). Fish morphologically resembling shortjaw cisco, and believed to be the same taxon, are found in several lakes outside of the Great Lakes basin extending from northern Ontario northwest to Great Slave Lake including several small lakes in Ontario, Lakes Winnipeg, Clearwater, George, and Athapapaskow in Manitoba, Reindeer Lake and Lake Athabasca in Saskatchewan, and Barrow Lake in Alberta. Figure 1 and Table 1 summarize the current reported distribution information for shortjaw ciscoes in Canada.

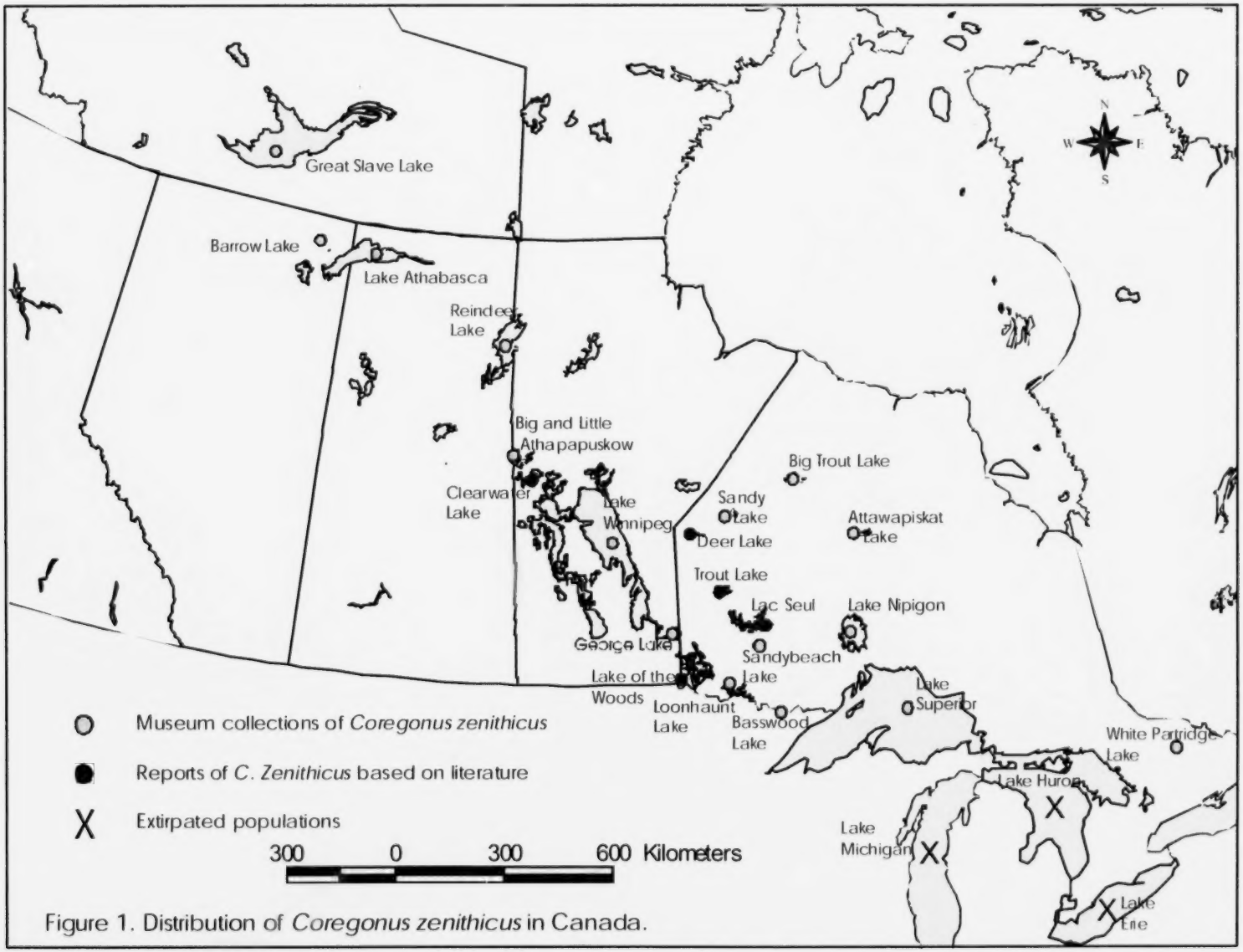

Figure 1. Distribution of *Coregonus zenithicus* in Canada.

Table 1. Reported occurences of *Coregonus zenithicus* in North America .

Location	Prov	Lat/Long	Reference	Museum	Valid presence of shortjaw cisco-like form
Great Slave Lake	NT	61° 37' N 114° 00' W	Harper and Nichols (1919) as *L.macrognathus* Dymond (1943) and Rawson (1947) as *C. zenithicus* Clarke (1973) as *C. artedi*	ROM	Uncertain, field work in 2000/2001 failed to find specimens
Barrow Lake	AB	59° 15' N 111° 14' W	Paterson (1969)	PMA,UAMZ,ROM	Yes
Lake Athabasca	AB	59° 15' N 110° 30' W	Dymond and Pritchard (1930)		Uncertain
Lake Athabasca	SK	59° 20' N 109° 00' W	Dymond and Pritchard (1930)	ROM	Yes
Reindeer Lake	SK	57° 14' N 102° 16' W	Bajkov (1930), Dymond (1943)	ROM	Yes
Big Athapapuskow L.	MB	54° 37' N 101° 39' W	Clarke (1970) *C. reighardi*, 1973 as *C.zenithicus*	ROM	Yes
Little Athapapuskow L.	MB	54° 37' N 101° 39' W	Clarke (1970) *C. reighardi*, 1973 as *C.zenithicus*	ROM	Yes
Clearwater Lake	MB	54° 05' N 101° 00' W	Clarke (1973)		Yes
Lake Winnipegosis	MB	52° 29' N 99° 59' W	Bajkov (1930)		No
Lake Winnipeg	MB	52° 08' N 97° 16' W	Bajkov (1930, 1932)	ROM	Yes, current status uncertain
George Lake	MB	50° 15' N 95° 30' W	Gibson and Johnson (1969) as *C. hoyi* Clarke (1973) as *C. zenithicus*	UMMZ	Yes
Lake of the Woods	ON	49° 16' N 94° 40' W	Hinks (1957)		Yes, current status uncertain
Big Trout Lake	ON	53° 45' N 90° 00' W	Ryder et al. (1964)	ROM	Yes, current status uncertain
Trout Lake	ON	51° 13' N 93° 19' W	Clarke (1973)	ROM	Yes, current status uncertain
Sandy Lake	ON	53° 02' N 93° 00' W	ROM as *C. hoyi* , Clarke (1973) as *C.zenithicus*	ROM	Yes, current status uncertain
Lac Seul	ON	50° 20' N 92° 16' W	Dymond and Pritchard (1930), Clarke (1973) changed to *C.zenithicus*		Yes, current status uncertain
Sandybeach Lake	ON	49° 48' N 92° 22' W	Wain (1993) MSc. U of Manitoba		Yes, current status uncertain
Loonhaunt Lake	ON	49° 01' N 93° 30' W		ROM	Uncertain
Basswood Lake	ON	48° 05' N 91° 35' W		ROM	Uncertain
Lake Attawapiskat	ON	52° 18' N 87° 54' W	Ryder et al. (1964)	ROM	No
White Partridge Lake	ON	45° 50' N 78° 06' W		ROM	Yes, current status uncertain
Lake Nipigon	ON	49° 50' N 88° 30' W	Koelz (1929)	ROM	Yes
Lake Superior	ON	48° 00' N 87° 00' W	Jordan and Evermann (1909) type species	ROM, UMMZ	Yes
Lake Michigan	ON	44° 35' N 86° 50' W	Koelz (1929)	ROM	Extirpated
Lake Huron	ON	44° 50' N 82° 25' W	Koelz (1929)	ROM	Extirpated
Lake Erie	ON	42° 00' N 81° 20' W	Koelz (1929)	ROM	Extirpated

STATUS OF SHORTJAW CISCO IN GREAT SLAVE LAKE, NORTHWEST TERRITORIES

EVIDENCE OF SHORTJAW CISCO IN GREAT SLAVE LAKE

Original Descriptions of Shortjaw Cisco in Great Slave Lake

In 1919 Harper and Nichols reported a new species of cisco, *Leucichthys macrognathus*, based on a single specimen collected from the shores of Great Slave Lake, Northwest Territories. Along with this species, they reported two other new species, *L. entomophagus* (from Tanzin River) and *L. athabascae* (from Lake Athabasca). Harper and Nichols (1919) counted the gillrakers of the three specimens and got counts of 41 for *macrognathus*, 35 for *athabasca*, and 33 for *entomophagus*.

In 1943 Dymond synonymized the above three species with *C. zenithicus* based on gillraker counts he made on the specimens of 37, 35 and 35 respectively as well as a small suite of characters. Dymond stated the gillraker count of 37 for *L. macrognathus* fell within the range reported by Koelz (1929) for shortjaw ciscoes in the Great Lakes region (32 to 46). Dymond also noted the above three specimens had low lateral line scale counts and long maxillaries, both characteristics of shortjaw cisco found by Koelz (1929). The three specimens were compared to collections of shortjaw cisco from Lake Nipigon, Lake Winnipeg, and Reindeer Lake using 20 morphological and meristic characters. Dymond found variation in many of the characters between populations, however, such findings are common when comparing Coregonines from different localities (Koelz 1929). Questions as to the validity of calling these specimens shortjaw cisco persist (Clarke 1973, McPhail and Lindsey 1970, Scott and Crossman 1973, Steinhilber 2000). Upon re-examination by Dr. J. S. Nelson the gillraker counts found by Dymond were considered to be too low. The actual counts were found to be similar to those originally reported (40- 41) by Harper and Nichols (1919), however, the specimens are reportedly too damaged to obtain exact counts today (Steinhilber 2000). When compared to the known ranges of characters for lake herring and shortjaw cisco, the Great Slave Lake specimen, *L. macrognathus* was found to resemble lake herring the most in its long gillrakers and short upper jaw. The gillraker count, short dorsal fin base and shallow head more closely resembled shortjaw cisco. Steinhilber's (2000) findings were not conclusive in identifying whether *L. macrognathus* was indeed the first reported shortjaw cisco from Great Slave Lake or a form of lake herring.

In 1947 Rawson reported that he collected two and maybe three cisco species during a survey of Great Slave Lake from 1944 to 1945. The ciscoes were caught in great numbers and were found to be heavily infested with *Triaenophorus*. In 1951 Dymond examined collections of ciscoes from 1944-45 for Rawson's Studies of the Fish of Great Slave Lake. Dymond determined there were at least three cisco species present in the sample, one was definitely lake herring, one resembled blackfin cisco, *C. nigripinnis*, and one was a larger species that could not be named. Further study failed to determine the specific identity of the third species and the author noted he was awaiting a revision of the genus in northwestern Canada by J. Keleher before confidently naming the other Great Slave Lake form (Rawson 1951). It was at this time that the cisco species of Great Slave Lake were grouped together for ease in reporting commercial fishery cisco catches, despite the knowledge of several species being present (Rawson 1951). As a

group, Rawson found ciscoes to be abundant throughout the entire lake, contributing greatly to the number of fish caught in the experimental gill nets. Ciscoes were caught in greater numbers than any other fish, accounting for 40% of the catch. When considering their weight, they had the third highest biomass, accounting for approximately 7% of the total weight. Rawson found ciscoes to occur from two meters to greater than 100 meters in depth with the majority caught between 26 and 75 meters. The most effective mesh sizes for catching ciscoes were 1.5 and 2 inch mesh with some ciscoes caught in larger-sized nets. He found cisco to be the main plankton eaters in the lake and an important forage fish for lake trout.

In 1930 Dymond and Pritchard listed the descriptive characters of *L. zenithicus* and mentioned *L. macrognathus* but they did not consider them to be synonymous. Lake Winnipeg and Lake Athabasca were listed as the only two bodies of water in western Canada having shortjaw cisco present.

In the 1940's a commercial fishery for lake whitefish and lake trout was begun on Great Slave Lake (Keleher 1972). Ciscoes were recorded as by-catch in most reports on the fishery with no attempts made to identify them to species. One data report from an experimental gillnetting program (Roberge *et al.* 1985) distinguished between lake herring and least cisco and also listed another cisco as Cisco spp., however, no descriptive information was reported. The majority of the reports for the fishery grouped the ciscoes together or failed to mention them at all. Ciscoes as a group appear to be abundant throughout the lake and abundance may have increased as a result of a decline in lake trout, the major predator of cisco, since the commercial fishery began (McPhail and Lindsey 1970). In Keleher's 1972 report on the effects of exploitation on the salmonid community, ciscoes were reported to be common but were not identified to species.

In 1973, Clarke identified one of six specimens collected from Great Slave Lake as a shortjaw cisco based primarily on a gillraker count of 38. Clarke (1973) described the species as being laterally compressed, having premaxillae at an angle similar to the snout, the tip of the lower jaw included in, equal to or projecting beyond the tip of upper jaw when mouth was closed, and variable pigmentation, often weak with pale fins. Shortjaw ciscoes were distinguished from sympatric lake herring by having fewer gillrakers, longer upper jaws and a lo nger snout. The shortjaw cisco specimen collected from Great Slave Lake was noted as having a more ovate profile and a shorter head than the lake herring specimens. Clarke (1973) considered shortjaw cisco to be present in Great Slave Lake based on these findings.

Scott and Crossman (1973) list Great Slave Lake as one of the lakes having populations of shortjaw cisco, however, they doubted the validity of *L. macrognathus* representing shortjaw cisco as previously suggested by Dymond. Scott and Crossman (1973) give a thorough description of shortjaw cisco including variation found between different water bodies for various characters such as gillraker counts and fin ray counts taken from previous studies (Koelz 1929, Hubbs and Lagler 1964).

Steinhilber (2000) studied a collection of putative shortjaw cisco from Barrow Lake, Alberta, which he compared to shortjaw ciscoes from other water bodies in North America. One of the samples consisted of eight specimens from Great Slave Lake. The gillraker range for these specimens was 37 to 44, the pectoral fin ray counts were 15 to 17 and the principal dorsal fin rays were 10 to 11. The Great Slave Lake population was

noted to have the shortest upper jaw, shorter craniums, more slender heads and relatively large dorsal fin bases compared to the other populations examined. The Great Slave Lake sample was found to overlap with several of the other samples when principal component analysis was applied. Information about who, when, and where these fish were caught was not available from the Royal Ontario Museum, where the fish are stored (M. Steinhilber, Provincial Museum of Alberta, Edmonton. pers. comm. 2002).

In 2000 Shawn Buckley (Hay River, NT) under contract with Fisheries and Oceans Canada collected 1071 ciscoes from the Hay River region of Great Slave Lake. A total of six sets were made at depths ranging from 13.7 to 23 meters. These specimens were collected as part of a Species at Risk Act assessment project attempting to verify the presence of shortjaw cisco in Great Slave Lake. In 2001 another 193 ciscoes were collected from around the Lutsel'ke region and 200 ciscoes from around the Simpson Islands region of Great Slave Lake. These collections were made by the author (L.M.) and Jim Johnson (Fisheries and Oceans Canada, Winnipeg) using fine mesh gill nets ranging in size from 10 to 60 mm mesh size (bar measure) and 60 to 120 m in length. Nets were set at varying depths (11 to 90 m) with the majority around 40 to 60 m.

Two cisco forms were considered present within the specimens collected from the Hay River region based on several meristic and morphometric characters including gillraker counts, maxillary length, body depth, fin length, and eye diameter. Total gillraker count was found to separate the two forms for the majority of individuals, however, some overlap was noted. One group consisted of 912 specimens having total gillraker counts of 46 or fewer. The other group consisted of 159 specimens with gillraker counts greater than 46. The lower gillraker group was found to have variable dorsal colouration ranging from light brown to dark blue. The fins were also found to have variable pigmentation ranging from dark black to nearly immaculate. The total gillraker count of the low group was found to range from 37 to 46 with an average standard length of 17 cm. While some individuals fell within the range of shortjaw cisco when compared to cisco populations from Manitoba both the low and high groups from the Hay River region were found to resemble lake herring and were not considered to be representatives of shortjaw cisco.

The 193 specimens collected from the Lutsel'ke region of Great Slave Lake consisted of a single form of cisco which was found to have a total gillraker count range of 36 to 55. Although some individuals had gillraker counts within the range of shortjaw cisco, other characters were consistent with those for populations of lake herring. Lake herring have been noted to have gillraker counts as low as 36, suggesting that the individuals caught from the Lutsel'ke region with low gillraker counts might represent lake herring and not shortjaw cisco (Scott and Crossman 1973).

The Simpson Islands specimens were found to consist of a single cisco form that was very similar to the Lutsel'ke ciscoes in appearance. The specimens ranged from light brown to dark blue in dorsal colouration and had dark pigmentation on their paired fins. The total gillraker count for this group ranged from 37 to 47 with the majority around 42. Characters such as lower and upper gillraker counts, eye diameter, lower arch length, snout length, and paired fin lengths were found to be similar to those for the other Great Slave Lake specimens mentioned above and lake herring populations from Manitoba. Based on this information the cisco specimens collected from the Simpson Islands region were considered to be lake herring.

Randy Eshenroder (Great Lakes Fishery Commission, Ann Arbor) collected cisco specimens from the Lutsel'Ke region in 2002. Some of these specimens were examined by Tom Todd (United States Geological Service, Ann Arbor) and he considered them to be similar to shortjaw cisco specimens from Lake Superior based on gillraker morphology, body form, head shape, and premaxillary angle.

Conclusion

The presence of a shortjaw cisco-like taxa in Great Slave Lake seems to be widely accepted by researchers. The descriptions mentioned above and the collection of specimens in the Royal Ontario Museum supports the presence of this form in the lake but current information is lacking to determine their status. Although recent attempts were unsuccessful at collecting shortjaw cisco specimens from various regions of the lake, it cannot be concluded that the species is not present. However, it does raise doubts about whether previously identified shortjaw ciscoes from Great Slave Lake might actually have been misidentified lake herring specimens with low gillraker counts. The designation of "May be at Risk" by the species monitoring program set up by the Northwest Territories Resources Wildlife and Economic Development Department seems suitable given the lack of information. Great Slave Lake is extremely large and the lack of distribution information makes it an expensive task to sample for shortjaw cisco without catching a large number of other fish in the process. COSEWIC designated the species as Threatened in 1987 and in 2000, shortjaw cisco became a species of special concern in the Northwest Territories due to their uncertain status in Great Slave Lake. Further study is needed to verify the presence of this species in Great Slave Lake, however, if they are present they do not seem to be abundant and perhaps not present in the Hay River or Simpson Islands regions of the lake.

DISTRIBUTION OF CISCOES IN GREAT SLAVE LAKE

Ciscoes have been caught throughout Great Slave Lake in large numbers since the commercial fishery began in the 1940's. No attempts were made to identify ciscoes caught to species making it a difficult task to determine their distribution. Rawson (1951) did not determine which cisco species he had collected in his study of the fish of Great Slave Lake but he did provide several locations where ciscoes in general were collected (Figure 2).

IMPACTS

Although the status of shortjaw ciscoes in Great Slave Lake is uncertain there are potential limiting factors that may influence them. The lake supports a year round, lake whitefish commercial fishery, which removes cisco as by-catch. Because no attempts are made to identify the ciscoes to species by fisherman, the contribution of each cisco species to the catch is unknown. The mesh size used in the commercial fishery has decreased over the years to accommodate the decrease in size of lake whitefish caught. The current legal minimum mesh size is 133 mm and by-catch may contribute up to 40% of the total catch. The lack of demand for these species usually results in them being culled on the lake. The majority of ciscoes caught as by-catch are large in size due to the large mesh size being used. Shortjaw cisco are known to vary in size from lake to lake and with little information being known about the biology of the species for Great Slave

Lake, the potential impacts of the commercial fishery on shortjaw cisco are unknown but may be significant. The commercial fishery has steadily decreased in recent years due to the low value of lake whitefish leading to the closure of several plants (J. Morin, Hay River, pers. comm., 2001). Potential impacts of climate change on northern lakes include a decrease in volume of deeper, colder waters (Reist 2000). Shortjaw ciscoes are usually found in deep, cold waters of lakes below the thermocline, thus decreases in the volume of this type of water would reduce the available habitat for the species. A reduction in available habitat may lead to introgression or hybridization as two seemingly separate species end up with overlapping niches. The overlap could cause a loss of any reproductive isolating mechanisms allowing the "species" to hybridize (Smith and Todd 1984). Given that we know very little about the status of the shortjaw cisco in Great Slave Lake it is difficult to assess the potential threats that exist for this species. The number of lake trout has decreased since the commercial fishery began which has undoubtedly reduced the predation rate on cisco (J. Morin, pers. comm., 2001). With little historic information available one can only speculate as to the impact the fishery has had on ciscoes, especially shortjaw cisco.

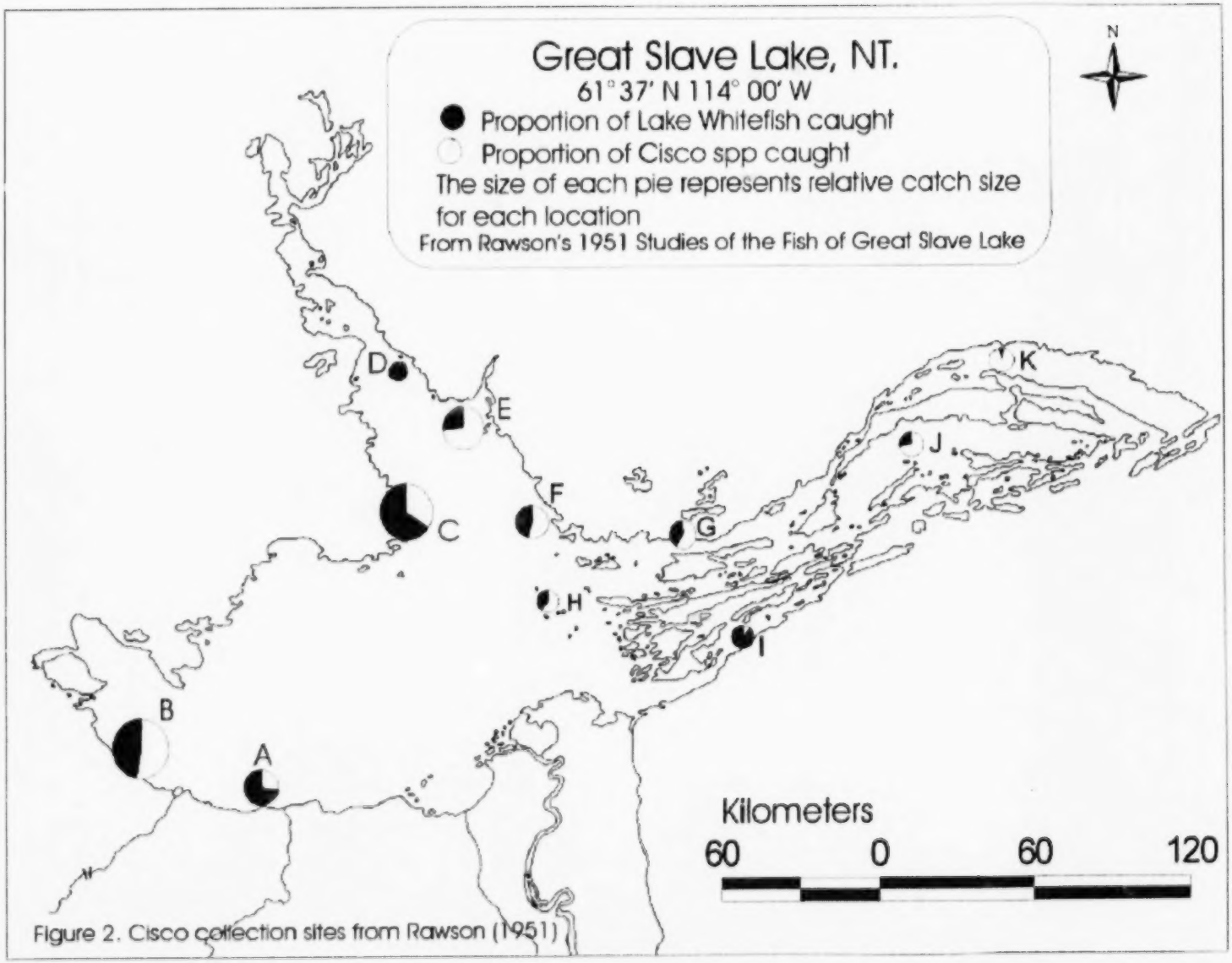

Figure 2. Cisco collection sites from Rawson (1951)

STATUS OF SHORTJAW CISCO IN LAKE ATHABASCA

EVIDENCE FOR SHORTJAW CISCO IN LAKE ATHABASCA

Original Descriptions of Shortjaw cisco in Lake Athabasca

The original report of a shortjaw cisco-like specimen from Lake Athabasca was reported in 1919 was by Harper and Nichols. The specimen was originally described as a new species, *Leucichthys athabascae*, and was caught at the mouth of the Charlot River in northern Saskatchewan. The specimen was 165 mm in length, had 11 dorsal rays, 12 anal rays, and had 35 long, slender gillrakers. The specimen was found in the stomach contents of a lake trout (Harper and Nichols 1919).

In 1930 Dymond and Pritchard described four specimens collected from Lake Athabasca, AB by G. C. Whiteley. They identified these as shortjaw ciscoes based on their long heads, large eyes, moderate snout length, long maxillary, long slender caudal peduncle, long fins, light colouration, and gillrakers numbering between 36 and 42. No reference is made to specific location where the collection was made (Dymond and Pritchard 1930).

In 1947 Rawson did an extensive study of Lake Athabasca focusing on the larger Saskatchewan side of the lake. The dominant fish in the lake were found to be lake whitefish, lake trout and two species of cisco. These fish were noted to be most common in the open water areas of the lake. Rawson (1947) suggested that there were two or possibly three species of cisco in the lake. Most of the fish collected were determined to be *C. artedi tullibee* based on their large, heavy bodies, locally referred to as tullibee (Rawson 1947). The other common form of cisco was identified as shortjaw cisco, which Rawson described as a small form of cisco with a long jaw and slender head. Rawson noted that shortjaw ciscoes were commonly found in the stomach contents of walleye, *Stizostedion vitruem* (Mitchell 1818), at the west end of the lake. The third possible species was blackfin cisco but Rawson was uncertain as to whether this represented a legitimate species or a form of lake herring. Rawson found that ciscoes as a group made up approximately 15% of the catch in test nets set in all parts of the lake. All of the ciscoes were found to be heavily infested with *Triaenophorus*, having an average of nine cysts per fish. Rawson (1947) suggested such a high infestation rate would give the ciscoes little economic importance other than as a major food fish for lake trout.

In Clarke's (1973) study of the Coregonine fishes of Central Canada he noted two forms of cisco from Lake Athabasca. The low gillraker form consisted of 18 specimens ranging in gillraker count from 34 to 43 with a mean of 38.7. The high gillraker form consisted of 26 specimens ranging in gillraker count from 49 to 57 with a mean of 52.6. The gillraker count variation alone between the two forms provided strong evidence for two species being present. When Clarke considered other characters such as body profile, premaxillary angle, maxillary length, eye diameter, and gillraker length he found more evidence to justify the distinction between the two forms. Based on these characters Clarke (1973) agreed with the previous findings that the high-raker form represented lake herring and the low-raker form represented shortjaw cisco in Lake Athabasca.

In 2001 collections were made by Mark Steinhilber (Provincial Museum of Alberta, Edmonton) on both the Saskatchewan (Black Bay region) and Alberta (south shore near border) sides of Lake Athabasca. A total of 152 cisco specimens were collected on the

Saskatchewan side and 51 were collected from the Alberta side. A preliminary examination of these specimens found two forms of ciscoes to be present based on gillraker counts, both forms were found to have average standard lengths around 150 mm. A sample of these specimens was sent to the Freshwater Institute in Winnipeg, MB where they were examined further for morphometric variation. A principal components analysis supported the findings of two forms. One form consisting of seven individuals had low gillraker counts, large gillraker spaces, long lower gill-arch lengths, long maxillary lengths, and long snout lengths. The second form consisted of 59 individuals with high gillraker counts, small gillraker spaces, short gill arches, short maxillary lengths, and short snout lengths. The low gillraker form was found to consist only of individuals from the Saskatchewan side of the lake with total gillraker counts of 29 to 35 and a mean of 33.4. The high gillraker form was found on both sides of the lake with total gillraker counts ranging from 36 to 57 with a mean of 42.6. Based on these findings the low gillraker form was considered to represent shortjaw cisco or a shortjaw cisco-like form while the high gillraker form was considered to represent lake herring. Although the presence of shortjaw cisco on the Saskatchewan side of Lake Athabasca is generally accepted, their presence on the Alberta side is unlikely given the lack of deepwater habitat. Further study is needed to determine the abundance of the shortjaw cisco-like form in Lake Athabasca and to confirm its absence on the Alberta side of the lake.

Conclusion

With limited information available on the cisco community it is difficult to determine the status of shortjaw ciscoes in Lake Athabasca. The above records confirm the presence of a shortjaw cisco-like form in Lake Athabasca on the Saskatchewan side. The current status of the shortjaw cisco is uncertain and further study is needed to shed some light on this subject for Lake Athabasca. The lake currently supports a commercial fishery, which may serve as a means of obtaining cisco information to answer some of the doubt surrounding cisco species in the lake.

DISTRIBUTION OF CISCOES IN LAKE ATHABASCA

Information about cisco distribution in Lake Athabasca is limited. Rawson's reports suggested that lake herring was common throughout the entire lake while shortjaw cisco were abundant but not to the extent of lake herring (1947). Specific distribution information is unknown, however, a map of the lake is attached (Figure 3).

IMPACTS

The lack of information about ciscoes in Lake Athabasca makes it difficult to speculate what factors may be limiting to these populations. Several factors known to influence shortjaw ciscoes in other lakes may pose similar threats to populations in Lake Athabasca. Commercial overfishing was a significant factor in the demise of cisco in the Great Lakes (Ono *et al.* 1983), however, the commercial fishery of Lake Athabasca has focused on lake whitefish and lake trout, rather than cisco. Ciscoes are considered by-catch and of no commercial importance given their high rate of parasite infestation. There is no information about the percentage each cisco species contributes to the commercial fishery. Without knowing this information we have no way of knowing the impact the fishery may have on the cisco community.

Lake Athabasca may be impacted by the effects of climate change. Potential effects from climate change are the decline in volume of cold, deep waters of great importance to the deepwater shortjaw cisco, and increased competition as suitable available habitat is lost (Reist 2000). If the abundance of shortjaw cisco and lake herring decrease then the potential for introgression may increase, which would likely result in the loss of one of the species from the lake. Loss of habitat is also a limiting factor but not a likely risk for the ciscoes in Lake Athabasca.

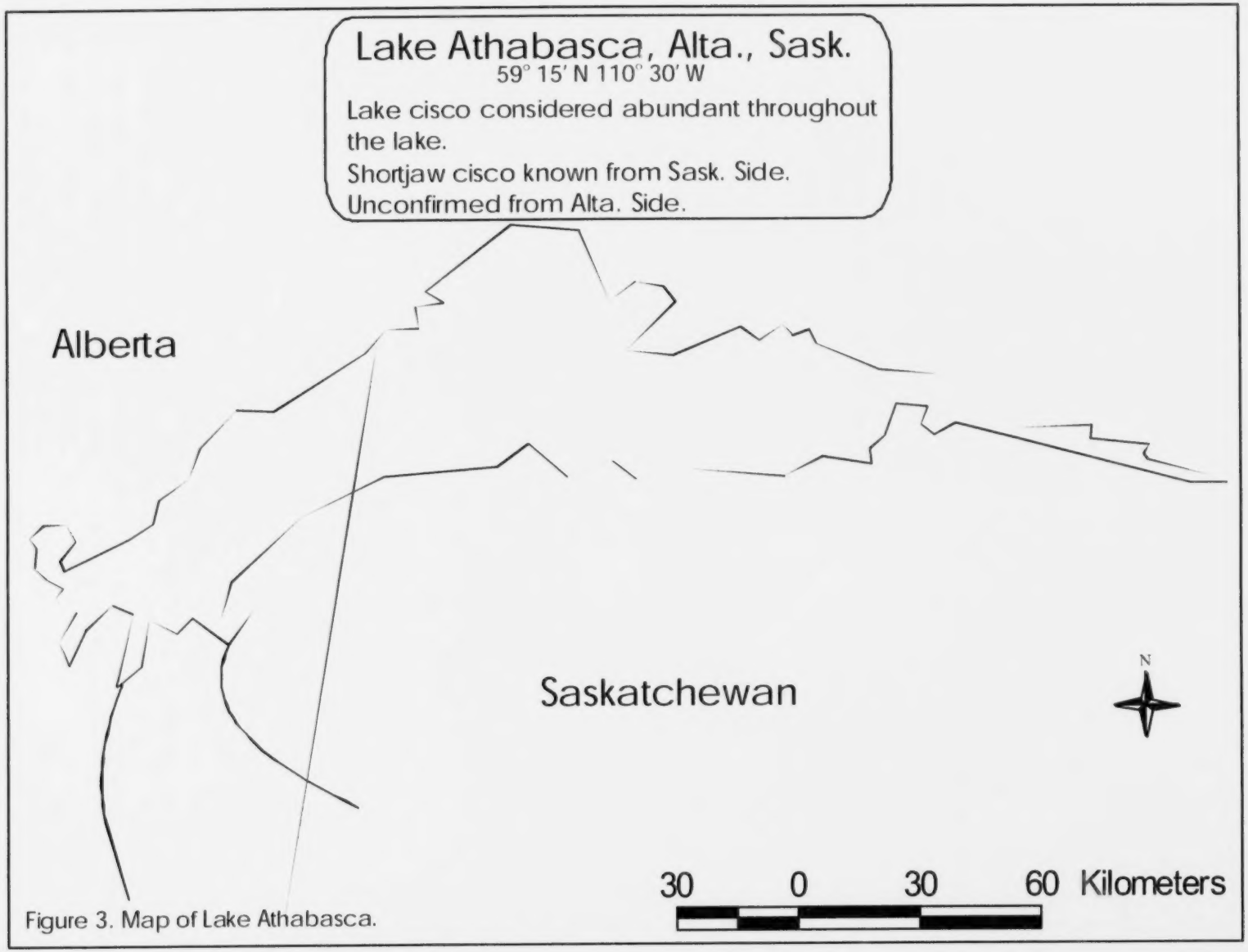

Figure 3. Map of Lake Athabasca.

STATUS OF SHORTJAW CISCO IN BARROW LAKE, ALBERTA.

EVIDENCE OF SHORTJAW CISCO IN BARROW LAKE

Original Description of Shortjaw cisco in Barrow Lake

In 1969 Paterson reported the occurrence of two species of cisco in Barrow Lake, a small northeastern Alberta lake. The ciscoes were effectively separated by gillraker counts and body size. Paterson (1969) found the larger individuals, which ranged in fork length from 27.7 to 46.7 cm, were most similar to shortjaw cisco in appearance. The smaller individuals, with fork lengths ranging from 16.8 to 20.8 cm, were considered to be lake herring based on descriptions by Dymond and Pritchard (1930) and Koelz (1929). When considering only the gillraker counts Paterson (1969) was able to completely separate the two species, with shortjaw cisco having gillraker counts ranging from 37 to 41 for 15 specimens and lake herring having 44 to 51 gillrakers for 21 specimens. The shortjaw cisco specimens were also found to have significantly longer snouts and predorsal lengths than the sympatric lake herring. The maximum size of the Barrow Lake shortjaw ciscoes was found to be greater than the previous maximum recorded size from the Great Lakes of 332 mm, reported by Koelz (1929) (Paterson 1969). Although the gillraker counts agreed with the designation of shortjaw cisco, several other aspects of this population of fish did not seem to fit into the usual description of a shortjaw cisco. Shortjaw ciscoes are usually slightly smaller or the same size as sympatric lake herring, however, the Barrow Lake population of shortjaw cisco was found to be considerably larger (Clarke 1973). Shortjaw ciscoes are usually a deepwater species occurring commonly at depths from 20 to 140 meters but has been noted to extend its range to shallower and deeper waters (Scott and Crossman 1973). In Barrow Lake the shortjaw cisco-like specimens were caught in nets set in 6 to 15 feet of water while the lake herring specimens were all caught in water deeper than 45 feet (Paterson 1969).

Clarke (1973) noted sympatric forms of ciscoes in Barrow Lake were easily distinguished morphologically. The lower gillrakered form was much larger and deeper bodied, and usually had a more vertical premaxillary angle than the higher gillrakered form. Despite noting the same differences from the general shortjaw cisco descriptions as Paterson (1969), Clarke (1973) also considered the low gillraker form of cisco in Barrow Lake to be shortjaw cisco.

The validity of Paterson's (1969) identification of shortjaw cisco in Barrow Lake was re-examined by Steinhilber in 2000. Paterson (1969) based his identification of the species primarily on gillraker counts and was unable to find many other characters useful in discriminating between the two forms. The gillraker counts obtained by Steinhilber (2000) from the 19 low gillrakered specimens ranged from 38 to 43 while the 332 high-rakered specimens ranged from 42 to 52. Steinhilber (2000) notes that Paterson used ratios to obtain quantitative shape differences, which sometimes masks differences between samples. Instead of relying heavily on a single or a few characters, Steinhilber (2000) found other characters, which could consistently separate out the two Barrow Lake forms. A shorter gillraker length, the position of the adipose fin, a smaller eye diameter and longer upper jaw were all found to be significantly different between the Barrow Lake low gillraker form and the high gillraker form, as well as ciscoes sampled from several neighbouring northern

Alberta lakes (Steinhilber 2000, Steinhilber *et al.* 2002). When compared to shortjaw cisco populations from elsewhere in North America, it was found that the Barrow Lake form was similar in most characters with a few exceptions. The dorsal fin base length of the Barrow Lake form was found to be greater than all other populations of shortjaw cisco and almost all populations of lake herring (Steinhilber 2000, Steinhilber *et al.* 2002). Dymond and Pritchard (1930) reported shortjaw cisco as commonly having a short dorsal fin base unlike this population. The gillraker length of the Barrow Lake shortjaw cisco was found to be shorter than the other populations he studied but reports of populations with short gillrakers not examined in the study exist (Steinhilber 2000, Steinhilber *et al.*2002). It was concluded that the low form from Barrow Lake represented putative shortjaw cisco based on their overall similarity to known populations of the species throughout their range (Steinhilber 2000, Steinhilber *et al.* 2002).

Conclusion

The taxonomic status of the low gillraker form of cisco in the lake seems to be answered, at least when considering morphological characters, however, genetic evidence has been inconclusive. Barrow Lake has a population of shortjaw ciscoes, however, they display some morphological and habitat differences from other putative shortjaw cisco populations (Steinhilber 2000, Steinhilber *et al.*2002).

DISTRIBUTION OF CISCOES IN BARROW LAKE

Unlike most lakes where shortjaw ciscoes are reported to occur, the Barrow Lake forms are found in similar depth or even shallower waters than the sympatric lake herring. Lake Nipigon has also been noted to have a shallow population of shortjaw cisco but not as shallow as Barrow Lake (T. Todd, pers. comm. 2002). The two forms of cisco are considered to be abundant throughout the entire lake (M. Steinhilber, pers. comm. 2002).

IMPACTS

Barrow Lake is a small lake in northern Alberta just north of Lake Athabasca. The lake has no commercial fishing and minimal recreational fishing so shortjaw ciscoes are not at risk from these factors. Steinhilber (2000) considers competition and introgression with sympatric lake herring to be the greatest risk to the continued existence of shortjaw cisco in Barrow Lake. Climate change may also pose a risk to shortjaw cisco as warmer temperatures may upset the ecological balance found in Barrow Lake. Although the population of shortjaw ciscoes in Barrow Lake does not rely on the colder, deepwater areas of the lake like most other shortjaw populations, the smaller lake herring do, which may cause increased competition and introgression as niches overlap. These factors, along with other anthropogenic factors should be monitored for future management strategies.

STATUS OF SHORTJAW CISCO IN REINDEER LAKE, SASKATCHEWAN.

EVIDENCE OF SHORTJAW CISCO IN REINDEER LAKE

Original Description of Shortjaw cisco in Reindeer Lake

In 1943, Dymond examined 13 cisco specimens collected from Reindeer Lake by Dr. D. S. Rawson of the University of Saskatchewan. Dymond identified these specimens as shortjaw cisco based on his previous cisco work (Dymond 1926, Dymond and Pritchard 1930). The average gillraker counts for ten of the Reindeer Lake specimens was 36 with no specimens having counts over 40 (Dymond 1943). Dymond also measured several other morpholo gical characters and compared them to specimens of shortjaw cisco from Lake Winnipeg and Lake Nipigon, as well as three species he considered to be synonymous with shortjaw cisco, now considered to be lake herring (McPhail and Lindsey 1970). The pelvic and pectoral fin lengths of the Reindeer Lake specimens were found to be similar to the Lake Nipigon shortjaw ciscoes while both were shorter than Lake Winnipeg shortjaw ciscoes (Dymond 1943). No information on where the Reindeer Lake shortjaw cisco specime ns were collected was given.

In 1973, Clarke examined five cisco specimens from Reindeer Lake and found them to have gillraker counts ranging from 34 to 38 with a mean of 35.6. Clarke (1973) was unable to obtain any ciscoes with higher gillraker counts, however, it was possible that the sampling effort was insufficient in providing representation of the cisco community of the lake. Along with low gillraker counts, these specimens were noted to have short gillrakers, a large premaxillary angle, long upper jaw, long snout, and a large eye diameter (Clarke 1973).

A total of 376 ciscoes were collected from Reindeer Lake in 2001 by the authors at depths ranging from 35 to 65 meters using 10 to 25 and 10 to 60 mm meshed nets. Three forms were found based on a principal components analysis using 27 meristic and morphometric characters. A high form consisting of 84 specimens with gillraker counts of 37 to 48 (mean of 41), long middle gillraker length, and low premaxillary angle (40.5° average). These individuals were found to have maxillary and snout lengths similar to those of the other two forms. The low form consisted of the greatest number of individuals (n=229), having total gillraker counts ranging from 23 to 32 (mean of 28), short gillraker lengths, large premaxillary angles (51.3° average), long maxillaries, and long snout lengths. The third form was referred to as the mid form and consisted of 63 specimens with total gillraker counts ranging from 32 to 39 (mean of 35.5), moderate gillraker lengths, large premaxillary angles (47.6° average), long maxillary lengths, and long snout lengths. Although these forms overlap in several of the above characters, the principal component plots completely separated the high form from the mid and low forms and the low and mid forms were found to overlap slightly. Pectoral and pelvic fin lengths were found to be longer in the mid form than the other two forms. When compared to key character descriptions from the literature (Dymond 1943, Clarke 1973, Scott and Crossman 1973) it was concluded that the low and mid forms most likely represented shortjaw cisco while the high form represented lake herring.

Conclusion

Based on specimens collected by Dymond (1943) and by the authors there is strong evidence supporting the presence of shortjaw cisco or a shortjaw cisco-like form within Reindeer Lake. A morphological comparison between the Reindeer Lake form and other low gillraker forms (Lake Athapapuskow, Clearwater Lake, and George Lake) found them to have several morphological similarities. Whether these similarities are due to genetic relatedness or phenotypic plasticity has not been determined. The low gillraker form was found to be abundant within the deepwater sets made by the authors.

DISTRIBUTION OF CISCOES IN REINDEER LAKE

The lack of information about ciscoes in Reindeer Lake makes it difficult to speculate what their current distribution may be. Early fisheries reports by the Saskatchewan government found ciscoes to be very abundant throughout the lake but there was no mention of shortjaw cisco and lake herring distribution specifically. A shortjaw cisco-like form and lake herring were caught around the Horseshoe Island region of Reindeer Lake in 2001. Future sampling in the lake is necessary to understand the current distribution of ciscoes in Reindeer Lake, however, given their abundance in the 2001 samples it would seem likely that putative shortjaw cisco populations occur throughout the lake where suitable habitat exists (i.e., depths greater than 30 meters). A distribution map of the lake is attached including the 2001 sampling location (Figure 4).

IMPACTS

Reindeer Lake is an isolated northern lake with a few small communities nearby that use the lake for subsistence fishing. The lake also supports a commercial lake trout and lake whitefish fishery. Ciscoes are caught as by-catch but types of species and amounts are not recorded (T. Housen, Saskatchewan Environment and Resource Management, La Ronge, pers. comm. 2001). The amount of ciscoes caught as by-catch has likely had little impact but other potential limiting factors may exist. The shortjaw cisco-like form was found to inhabit the deeper regions of Reindeer Lake. Reindeer Lake may be impacted by climate change effects such as a decrease in the volume of cold, deep waters commonly inhabited by shortjaw cisco and by the increased competition that this would cause as suitable habitat becomes more scarce. Further study of the cisco community of Reindeer Lake is necessary to determine their status and if they are at risk or not.

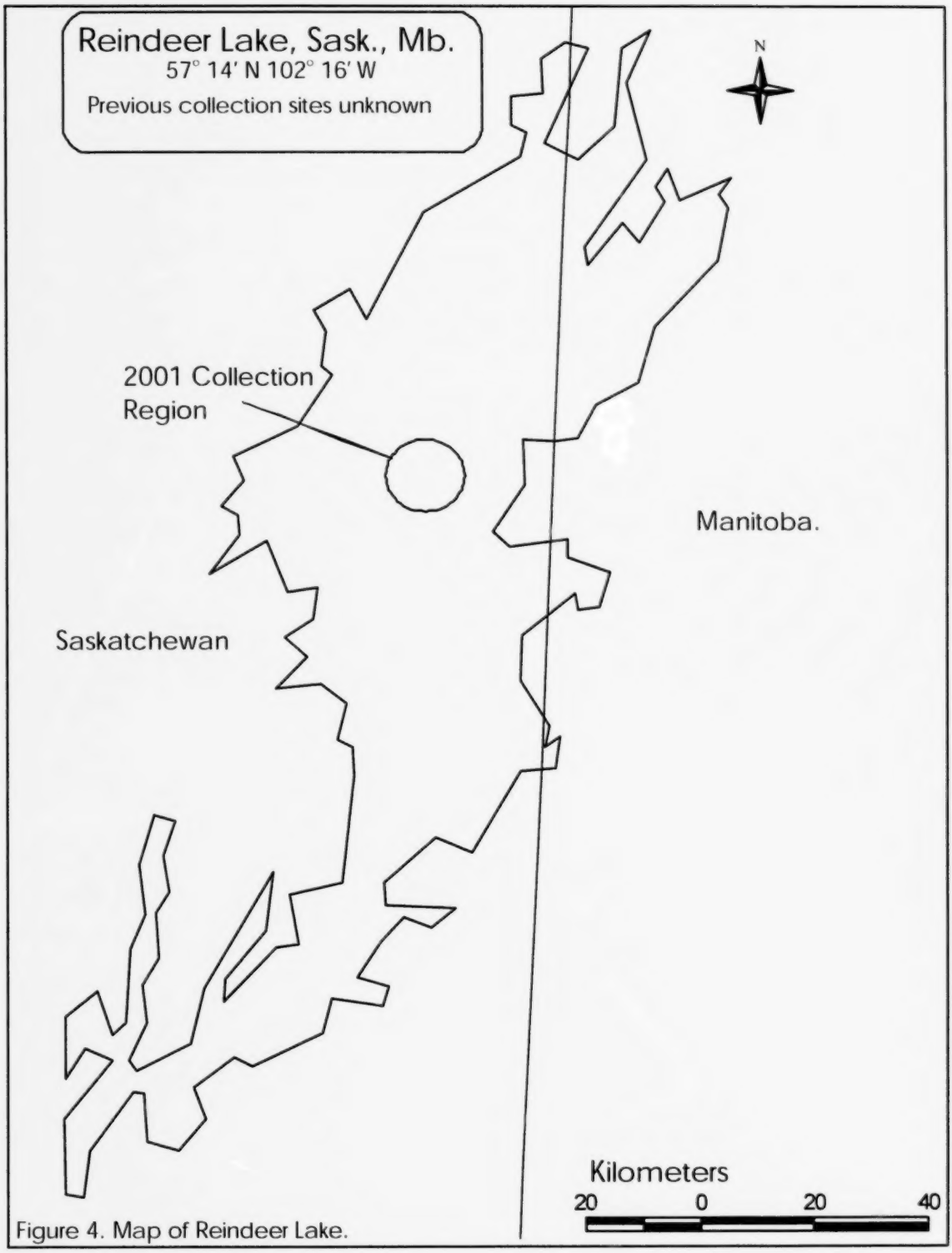

Figure 4. Map of Reindeer Lake.

STATUS OF SHORTJAW CISCO IN LAKE ATHAPAPUSKOW, MANITOBA

EVIDENCE OF SHORTJAW CISCO IN LAKE ATHAPAPUSKOW

Original Description of Shortjaw cisco in Lake Athapapuskow

In 1973, Clarke studied the cisco fauna of Lake Athapapuskow and first identified shortjaw cisco in the region. Three years earlier Clarke (1970) studied the same region and identified the low gillraker cisco he found to be *C. reighardi* based on descriptions from the Great Lakes (Koelz 1929, Hubbs and Lagler 1964). Clarke (1973) examined at the lake in sections, referring to the large southern basin as Big Athapapuskow, the smaller mid basin as Little Athapapuskow and a section of channel connecting the two basins as Mink Narrows. A low gillraker form of cisco was collected at each of these locations along with several sympatric forms of lake herring (Clarke 1973). The 16 low gillraker specimens collected from Big Athapapuskow had gillraker counts from 24 to 36 with a mean of 29.5, while two forms of high gillraker cisco were collected with counts ranging from 38 to 47 and 42 to 49. Clarke (1973) described the lower form as greenish in colour above the lateral line, and lower jaw included in upper and nearly vertical premaxillae. In Clarke's (1970) previous study he found 30% of the high gillraker form to have protruding lower jaws, 44% in the medium form, while 78% of the lower form had a shorter lower than upper jaw. The gillraker counts for the low form in Big Athapapuskow are below the normal range for shortjaw cisco, especially the count of 24, which may represent a counting error, a damaged arch or a mutation (Clarke 1973). The gillraker count in the low group was most similar to *C. reighardi*, which Koelz (1929) distinguished from *C. zenithicus* by its ovate profile and low gillraker counts. Both these characters were noted by Koelz (1929) to vary between and within populations, leading Clarke (1973) to reclassify the Athapapuskow low form as shortjaw cisco.

In Little Athapapuskow three forms of cisco were also collected, a low form consisting of 14 specimens with gillraker counts from 32 to 37, a mid-count form with counts from 40 to 46 and a high form with counts from 48 to 54 (Clarke 1973). Clarke (1970) previously identified the low form as *C. reighardi*, which he changed to *C. zenithicus* following a broader look at the characters and overall similarity to other populations of shortjaw cisco (Clarke 1973). In Mink Narrows Clarke (1973) again found three possible forms of cisco, eight specimens of a low form with 34 to 40 gillrakers, 20 mid-count specimens ranging from 43 to 47, and a single high form with 58 gillrakers. The low form, along with the other shortjaw cisco characters previously mentioned, was noted as having a shallower body than did the higher forms.

In 1996 Little Athapapuskow was sampled by Bob Fudge and Jim Johnson (Fisheries and Oceans Canada, Winnipeg) in an attempt to find shortjaw ciscoes. Two forms of cisco were identified as lake herring based on gillraker counts. One form ranged from 35 to 42 while the other form ranged from 42 to 48. Two individuals were noted as having counts of 52 and 54. Although the low gillraker form seems to have a similar range to Clarke's (1973) study, the fish were found to lack other distinguishing shortjaw cisco characters such as a large premaxillary angle, long maxillae and long snout (R. A. Bodaly, Fisheries and Oceans Canada, Winnipeg, pers. comm. 2002).

In October 2000 sampling was conducted in the three deepest regions of Big Athapapuskow and the deepest region of Little Athapapuskow by the authors. A total of 189 ciscoes were collected and three forms were initially noted. The high form consisted of 114 specimens with gillraker counts ranging from 36 to 47 (mean of 40), long gillraker lengths, low premaxillary angles (42.3° average), short maxillary lengths, and moderate snout lengths. The low form consisted of 64 individuals with total gillraker counts from 22 to 35 (mean of 28), short gillraker lengths, large premaxillary angles (48.7° average), long maxillary lengths, and long snout lengths. The mid form was the only form collected from Little Athapapuskow and consisted of 11 specimens with gillraker counts ranging from 32 to 37 (mean of 34), short gillraker lengths, large premaxillary angles (46.8 average), moderate maxillary lengths, and long snout lengths. When principal component analysis was performed using 26 meristic and morphometric characters, complete separation was found between the high form and the other two forms. The low form completely overlapped the mid form. These findings led us to believe that the high form represented lake herring, while the low and mid forms both represented morphotypes of a shortjaw cisco-like taxon.

Conclusion

It is apparent that a low gillraker form cisco resembling shortjaw cisco is present in Lake Athapapuskow based on previous and recent studies. Preliminary morphological analysis has determined that this form of putative shortjaw cisco is similar to those in other water bodies such as Clearwater Lake, George Lake, and Reindeer Lake. From Clarke's (1973) work and personal observations by the author, the ciscoes in Lake Athapapuskow seem to be abundant and probably represent stable populations.

DISTRIBUTION OF CISCOES IN LAKE ATHAPAPUSKOW

Putative shortjaw ciscoes are found in the deeper regions of Big Athapapuskow along with some lake herring forms. The full extent of the shortjaw cisco distribution is uncertain but based on personal observations it is likely present wherever conditions are favourable for lake trout and lake whitefish. The lake herring were present in the deeper waters with shortjaw cisco but they likely inhabit shallower waters as well. Further study is needed to determine more information about abundance and distribution of the cisco species in Lake Athapapuskow. Attached is a map showing depth contours in meters (Figure 5; taken from Day 1983).

IMPACTS

Lake Athapapuskow supports a small commercial lake whitefish fishery and a popular recreational fishery aimed primarily at lake trout. Neither of these likely have much impact on the cisco community. The loss of lake trout may increase the abundance of cisco in the lake due to decreased predation, however, the lake trout fishery is currently stable. The affects that climate change may have on Lake Athapapuskow involve the loss of cold, deep water habitat where shortjaw cisco are usually found. This would likely cause increased competition with sympatric coregonine species as the amount of suitable habitat is reduced. The presence of three forms in the same habitat suggests they are reproductively isolated taxa, however, hybridization between the sympatric forms is possible and may lead to the loss of one or more of these forms.

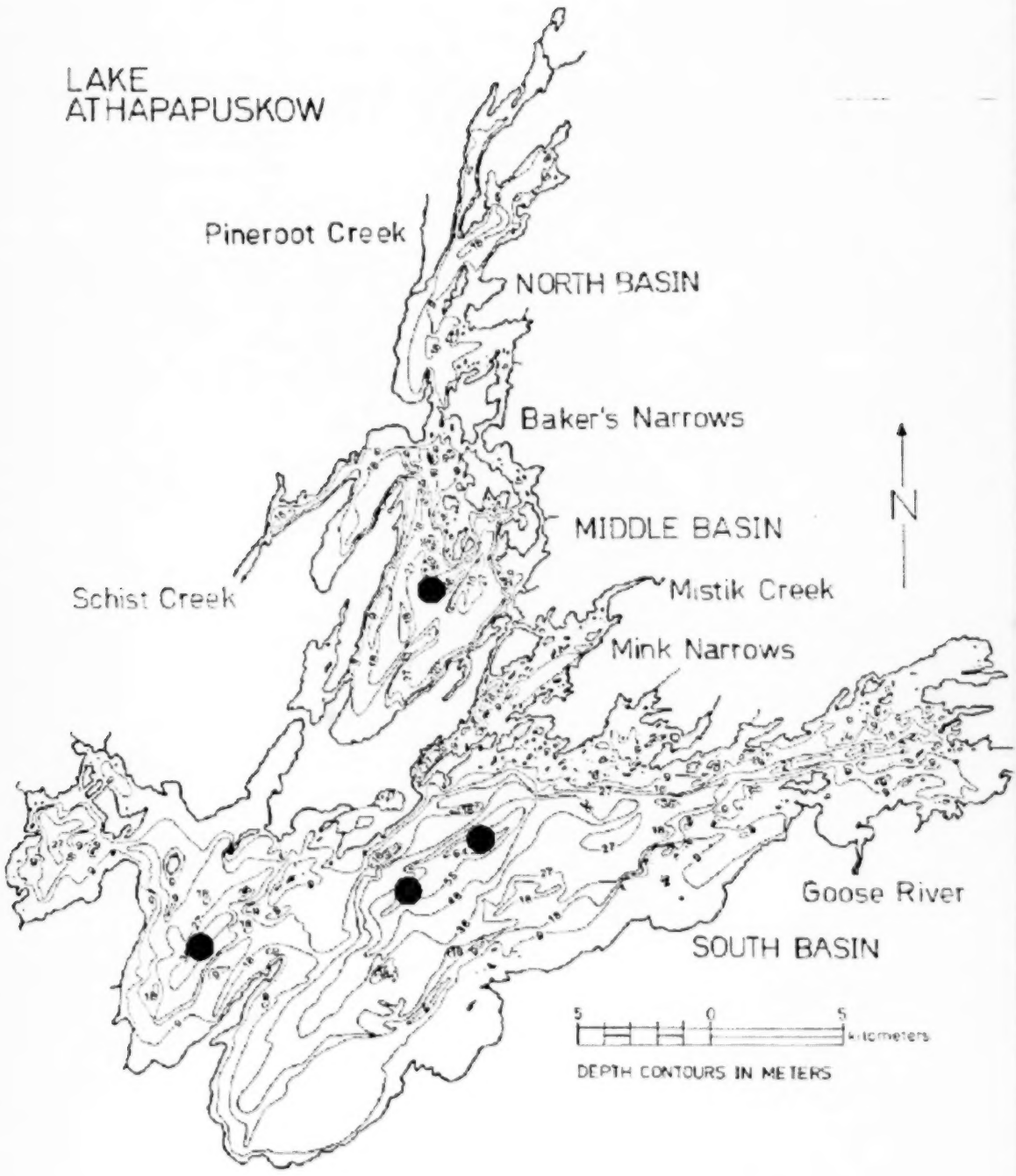

Figure 5. Lake Athapapuskow map (Day 1983). Note: 2000 collection sites indicated by dots.

STATUS OF SHORTJAW CISCO IN CLEARWATER LAKE, MANITOBA

EVIDENCE OF SHORTJAW CISCO IN CLEARWATER LAKE

Original Description of Shortjaw cisco in Clearwater Lake

In 1973, Clarke reported two specimens of cisco collected from Clearwater Lake both with gillraker counts of 33. Clarke (1973) also collected 28 cisco with gillraker counts from 38 to 49. The low form was found to have shorter gillrakers than the high gillraker form. Clarke (1973) identified the low form to be shortjaw cisco based on the low gillraker count, large premaxillary angle, long upper jaw, large eye diameter and long snout.

In October 2000 Clearwater Lake was sampled by the author (L.M.) and Jim Johnson in an attempt to obtain shortjaw cisco specimens. Two nets were set in the deepest region of the lake (40.5 and 32.5 meters) and 24 ciscoes were collected. At the time of capture none of these specimens showed distinct shortjaw cisco-like characters. Further analysis revealed that 16 of the specimens had low gillraker counts (from 31 to 37 with a mean of 35) while eight others had counts of 39 to 42. A histogram of gillraker counts for the Clearwater Lake specimens showed bimodality, however, the sample size was too small to come to any definite conclusions. The low form was found to have a slightly longer dorsal fin base length, longer maxillaries, and a greater eye diameter than the high form, characters found to be representative of putative shortjaw cisco populations (Scott and Crossman 1973, Steinhilber *et al.* 2002, Todd and Steinhilber 2002).

Conclusion

Information about the cisco community of Clearwater Lake is limited, making it difficult to determine their status. A shortjaw cisco-like taxa seems to be present in Clearwater Lake and preliminary morphological analysis has found it to be similar to low gillraker forms from Lake Athapapuskow, George Lake, and Reindeer Lake. Clarke's (1973) work was an important step towards understanding the cisco diversity within Clearwater Lake. Hopefully morphological and genetic work can take this understanding further.

DISTRIBUTION OF CISCOES IN CLEARWATER LAKE

No previous information was available about cisco distribution in the lake. The 2000 sampling by the authors was done in the deepest regions we could find with bottom-set gill nets. The lack of ciscoes in this collection may be accounted for by the time of year in which the sampling was done. The collections were made in mid October, which may be spawning time for shortjaw cisco and lake herring in the lake. Shortjaw ciscoes have been noted to spawn in shallower waters in the fall ranging from September to late November depending on the water body (Scott and Crossman 1973). Spawning information about Clearwater Lake ciscoes is unknown, making it possible that the majority of cisco in the lake had moved to shallower waters to spawn. A map of Clearwater Lake is provided showing depth contours and collection sites from 2000 (Figure 6).

IMPACTS

Clearwater Lake had a commercial lake whitefish fishery and ciscoes contributed minimally to the fishery as by-catch making risk of overfishing an unlikely limiting factor. Climate change may impact the lake causing a reduction in the cold, deep water habitat. Shortjaw ciscoes have been found to occupy these habitats and a reduction would likely cause increased competition with sympatric lake herring and lake whitefish. The risk of introgression with closely related lake herring is a potential limiting factor, further study would be beneficial in determining how closely related these species are and to what extent they share habitat. Other potential limiting factors may exist so the lake should be monitored to ensure the species composition remains stable and the shortjaw cisco remains as part of the cisco community.

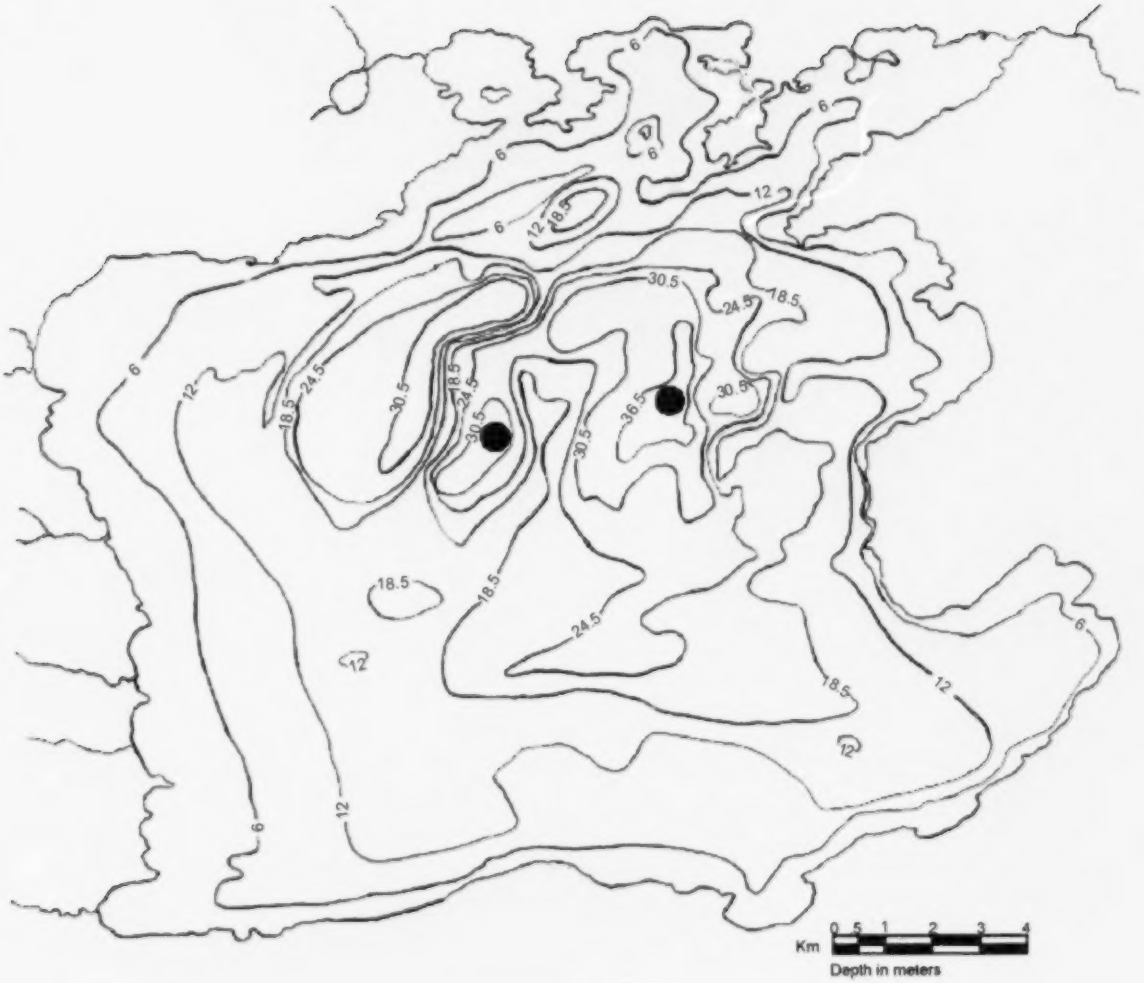

Figure 6. Bathymetric map of Clearwater Lake, Note: 2000 collection sites indicated by dots.

STATUS OF SHORTJAW CISCO IN LAKE WINNIPEG

EVIDENCE OF SHORTJAW CISCO IN LAKE WINNIPEG

Original descriptions of Shortjaw cisco in Lake Winnipeg

In 1930 Bajkov described several forms of tullibee present in lakes Winnipeg, Manitoba, and Winnipegosis. Based on the observations of local commercial fisherman he obtained six different common names used for the various forms of tullibee caught: tullibee, black-backed tullibee, light-backed tullibee, green-backed tullibee, silver-backed tullibee and red-fin tullibee (likely a whitefish hybrid). Of these Bajkov (1930) noted black-backed and light-backed to be the most common and most easily distinguished. Of the light-backed forms the most dominant species was considered to be *C. zenithicus*, shortjaw cisco, having long jaws and gillraker counts ranging from 35-41. Although Bajkov (1930) called the dark-backed forms *C. tullibee* and *C. nipigon* they are now considered to be different forms of *C. artedi*, lake herring (Clarke 1973).

Bajkov (1930) stated the growth rate of the dark-backed tullibee was much faster than the light-backed tullibee based on age and length comparisons of one hundred fish. The primary source of food for shortjaw cisco was found to be amphipods (*Pontoporiea hoyi*) and larvae of aquatic insects (*Chironomus, Hexagenia,* etc.). Bajkov (1930) found *C. zenithicus* to spawn in the fall in Lake Winnipeg, usually once they reached age three or greater with an average fecundity of 15-20 000 eggs. The black-backed tullibees were found to reach a greater length at the time of first spawning (300 mm) than the light-backed tullibee (250 mm). Bajkov (1930) stated both the light-backed and black-backed tullibee were widely distributed throughout lakes Winnipeg and Winnipegosis but had different habitats. The light-backed tullibee was found to prefer shallow waters along the shores and bays of Lake Winnipeg where 75% of commercial catches were accounted for by light-backed forms (Bajkov 1930). At the time of Bajkov's (1930) study of the commercial fisheries in Manitoba the tullibee fishery was one of the most important operations during fall and winter with 7,000,000 lbs. coming out of Lake Winnipeg per year on average.

In 1930 Dymond and Pritchard noted shortjaw cisco as being present in Lake Winnipeg based on collections made by A. Bajkov in 1927. They described the species as having a moderately long head, very large eye, moderate snout, long maxillary, long and slender caudal peduncle, fairly long fins, lateral line scales from 58-69 and gillraker counts of 13 + 25 (12 + 22 to 14 +26). Similar to Bajkov (1930), they found shortjaw cisco to be the lightest coloured cisco species along with normally having immaculate fins.

In 1932 Bajkov reported that the light-backed form of tullibee or cisco from Lake Winnipeg consisted almost entirely of shortjaw cisco while the dark-backed tullibee consisted of several species. In his key the distinguishing characters for shortjaw cisco were gillraker counts on the first branchial arch ranging from 33-42, large eyes, light colour when living, pale paired fins, firmly attached scales, elliptical body and bottom feeding nature. Two years after his initial report of shortjaw ciscoes being present in Manitoba lakes other than Lake Winnipeg, Bajkov (1932) stated they were only found in Lake Winnipeg with any certainty. Bajkov (1932) examined 400 specimens from Lake Winnipeg he considered to be shortjaw cisco based primarily on gillraker counts from 31 to 44. Bajkov (1932) referred to this species as being the most desirable cisco species commercially given its large size and

its decreased rate of infestation with parasites as compared to the other ciscoes. Unlike his 1930 report, Bajkov (1932) referred to this species as being predominantly found in deep waters where soft mud bottoms occur. Shortjaw cisco were found to be more abundant along the western shores of the lake and in the summer was noted to form large schools separate from other cisco based on catch data.

In 1943 Dymond compared various collections of shortjaw cisco from Lake Nipigon, ON, Lake Winnipeg, MB, and Reindeer Lake, SK, to three new species found by Harper and Nichols (1919). When compared to these other populations he found the Lake Winnipeg specimens to have considerably longer fin lengths than Lake Nipigon and Reindeer Lake specimens but the remaining characters were found to be similar. He also considered the three new species to be synonymous with shortjaw cisco, however, this remains a questionable classification to date (Steinhilber 2000).

In 1943 Hinks reported on the different cisco forms found in Manitoba. At the time six species cisco species were recognized in his key including *C. nipigon, C. nigripinnis, C. tullibee, C. artedi, C. hoyi,* and *C. zenithicus*. The species were identified primarily by gillraker counts with *C. hoyi* and *C. zenithicus* being identified as ciscoes having less than 43 gillrakers, *C. artedi, C. tullibee,* and *C. nigripinnis* had 43 to 54 gillrakers, and *C. nipigon* had 55 or more. *C. zenithicus* was distinguished from *C. hoyi* as being larger and having a thick mandible lacking a hook at the end. The high gillraker group was separated based on head length and body depth variation. Hinks (1943) noted that tullibee were frequently found to be intermediate between forms and that even whitefish and tullibee had been found to hybridize under hatchery conditions at Dauphin River. Hinks (1943) described shortjaw cisco as a relatively deep water species in Lake Winnipeg, occurring in large schools primarily along the western side of the lake.

In 1947, Keleher studied the tullibee of northern Lake Winnipeg more extensively (Keleher 1948). The light-backed and dark-backed forms were both present but he found it difficult to distinguish between them unless they were freshly caught and even then he was not always certain. The light-backed tullibee again were found to have low gillraker counts ranging from 34 to 42 while the dark-backed tullibee ranged from 43 to 67. He also found the light-backed tullibee to be smaller in size on average with 97% of the specimens in the 34 to 42 gillraker range, being under 275 mm. During the summer, Keleher found the light-back tullibees were abundant in the waters surrounding Commissioner and Hecla Islands. During the fall when the light-backed tullibee spawned they were found in shallow waters around Fisher and Sturgeon Islands. Light-backs were also collected seven miles east of the Big Black River fishing stations at a depth of 12 meters above a soft clay bottom (Keleher 1948).

In 1950 Keleher reported on the occurrence of tullibee species in northern Lake Winnipeg once again. The various species were determined based on Dymond's (1943) key which relied mainly on gillraker counts along with head length to some extent. Shortjaw ciscoes were considered to be all specimens having 43 or less gillrakers on the first branchial arch. In 1947, 271 shortjaw cisco specimens were caught at Mukatawa River along with 220 lake herring (originally listed as three different species, now only lake herring and shortjaw cisco are considered to be present in western Canada). In 1948, 119 shortjaw cisco were caught at Mukatawa River along with 77 other tullibee. In 1949, only 41 shortjaw cisco and 29 lake herring were caught at the same location. The collections from Mukatawa River in 1947, 1948 and 1949 were made by commercial fisherman targeting whitefish who

obtained these tullibee as by-catch in their 5.25 inch stretched-mesh nets. The 1948 collections were made using 1.5 and 3 inch mesh, commercial fisherman by-catch and, in the case of Matheson Island, a local resident donated cisco he had caught (Keleher 1950). The average size of shortjaw cisco specimens taken in this study was between 220 to 260 mm, with few exceeding 300 mm (Keleher 1950).

In 1950, Keleher studied the spawning behaviour of Lake Winnipeg tullibee at Doghead Bay. Gill nets were set from November 4th to 16th in open water at 24 feet and then after freeze-up on the 21st the nets were set under the ice at depths of 15-17 feet and 39-42 feet. Of the 421 ciscoes collected, Keleher identified 55 % to be shortjaw ciscoes. Spawning was noted to occur mainly after freeze-up in this region of the lake with shortjaw ciscoes spawning at the shallower depths to a greater extent than the other ciscoes (Keleher 1950).

In 1951, Keleher continued his work on the taxonomic status of tullibee in Lake Winnipeg by studying the meristic characters of the specimens he obtained from previous studies. The meristic characters studied included dorsal and anal fin rays, number of branchiostegal rays, and vertebral counts. The meristic characters were compared between *C. zenithicus*, *C. nigripinnis* and *C. nipigon* by finding interspecific differences of the mean and variance for each character (Keleher 1951). No difference was found between the species in the number of vertebrae. All species differed in branchiostegal rays and shortjaw ciscoes were found to be significantly different from the other two when considering the average number of dorsal and anal fin rays. Although Keleher found some differences between the species using these characters, he considered the differences to be so slight that they provided little use for identificatio n purposes (Keleher 1951).

In 1973 Clarke examined Lake Winnipeg specimens from the University of Manitoba zoology museum (UMZM) and the Royal Ontario Museum (ROM). The nine specimens from the UMZM had gillraker counts ranging from 38 to 47 while the five ROM specimens ranged from 37 to 43 (Clarke 1973). Clarke (1973) also examined the higher gillrakered species found in Lake Winnipeg and considered them to be four sympatric forms of lake herring along with one form of shortjaw cisco. Distribution information was not presented in Clarke's (1973) study but given that he used museum specimens it is likely these were either collected by Bajkov or Keleher, whose collection sites were mentioned above.

In 2000 Steinhilber looked at eleven Lake Winnipeg shortjaw cisco specimens from the ROM. These specimens were compared to eight other populations of shortjaw cisco and found to have a relatively small upper jaw and short cranium. The gillraker count range was 36 to 41 with a mean of 38.4, the range for all the populations combined was 30 to 46 with a mean of 38.7. A principal components analysis of six morphometric variables grouped the Lake Winnipeg specimens closely with the majority of putative shortjaw cisco populations (Steinhilber 2000).

Conclusion

Although early studies by Bajkov in the 1930's and Keleher in the 1950's greatly increased our knowledge of the Coregonine situation in Lake Winnipeg, little current information is available. Work done on ciscoes in the lake in the last 30 years has relied on museum specimens. We can be certain a taxon representing shortjaw cisco was present in Lake Winnipeg but without current information its current status is unknown. Commercial

fishing records do not distinguish between tullibee species but they may provide a valuable source of information if we can determine the present contribution each tullibee species makes to the commercial by-catch. To do so commercial catches must be obtained and analyzed to determine which species are present and to what extent. Once that information is determined then we may be able to estimate how abundant the shortjaw cisco is in Lake Winnipeg. If no shortjaw cisco are found in the catches then several factors may have occurred: 1) the shortjaw cisco may no longer be present in Lake Winnipeg, 2) the gear used by the fisherman was ineffective at catching shortjaw cisco and therefore they are not at risk from overfishing, 3) the region fished may not have shortjaw cisco present in it at that time but they may be present elsewhere in the lake. The work done on Coregonines in Lake Winnipeg confirms the presence of shortjaw ciscoes or a shortjaw cisco-like form in the lake but further work is needed to determine the extent of this species today. Figure 7 shows the annual Lake Winnipeg cisco production record since 1883. The fishery has declined from nearly 3 500 000 kg in 1927 to under 500 000 kg in 1972 to less than 1000 kg since 1987 (Manitoba Conservation). The historic decrease in commercial cisco catch was due to the high amount of parasite infestation in the Lake Winnipeg ciscoes.

DISTRIBUTION OF CISCOES IN LAKE WINNIPEG

The current distribution of ciscoes in Lake Winnipeg is unknown but commercial fishing records suggest they are common throughout most of the lake. Bajkov and Keleher collected a large amount of information on the distribution of each species shown in Figure 8. It should be noted this information is at least 50 years old and dramatic changes to the distribution of ciscoes may have occurred since. Monitoring of commercial by-catch and experimental gill netting is necessary to get an up to date picture of the distribution of cisco species in Lake Winnipeg.

IMPACTS

Lake Winnipeg has supported commercial fisheries primarily aimed at walleye and lake whitefish since the 1930s. Tullibee have contributed to these commercial fisheries as shown in Figure 10. Although once making up a major proportion of the catch in these fisheries, the amount of tullibee production has declined dramatically since the 1930's when they were discovered to be heavily infested with parasites. The current mesh-size regulations for Lake Winnipeg range from 76 mm to 127 mm with the majority of regions in the lake having a restriction of 108 mm. The lack of tullibee caught recently suggests: 1) the size of tullibees in the lake is too small to be caught in the current mesh size being used, 2) the number of tullibee in the lake has been greatly reduced so they are uncommonly caught, 3) commercial fishing is occurring primarily in regions of the lake where tullibee are uncommon, or 4) they are caught as by-catch and not reported. In order to understand the situation better the commercial fishery needs to be monitored for any information about tullibee caught, including species, size, age, location, depth in the water column, stomach contents, etc. The negative impact of the fishery on tullibee in general is apparent but the specific impact on shortjaw ciscoes is unknown. As previously noted shortjaw cisco represents the smallest tullibee in Lake Winnipeg which may have prevented it from being caught to any great extent in the commercial gill nets but this needs confirmation.

Another potential impact which was a factor in the decline of ciscoes in the Great Lakes and may be a limiting factor in Lake Winnipeg is competition with non-native

species. The rainbow smelt was first reported from Lake Winnipeg in 1991 within the stomachs of walleye (Remnant 1991). Based on the impact this invading species has had in other lakes, such as declines in lake whitefish and ciscoes, Lake Winnipeg is anticipated to also see decreases in its natural fish composition. The rainbow smelt situation must be monitored closely to determine the extent of their presence in the lake and surrounding waters.

Lake Winnipeg ciscoes may also be at risk from the impacts of increased nutrient levels being recorded within the lake. Phosphorous and nitrogen levels are increasing within the lake due to insufficient water treatment standards along the Red River and its tributaries, which flow into the southern basin of Lake Winnipeg. The increased nutrient levels have caused large algal blooms in the northern basin and increased turbidity throughout the lake. Coregonine numbers may increase initially due to a greater abundance of benthic invertebrates which they prey upon. When the algal blooms subside the invertebrates will die off in great numbers and accumulate in the benthos, causing poor benthic feeding conditions and loss of prey species for ciscoes and whitefish (A. Kristofferson, Fisheries and Oceans Canada, Winnipeg, 2003). Shortjaw ciscoes have been found primarily in the deepest regions of lakes, with Lake Winnipeg's estimated maximum depth of 18 meters, a loss of suitable benthic habitat would likely force shortjaw ciscoes into the mid-water habitat commonly occupied by lake herring resulting in increased resource competition.

Since 1976 Lake Winnipeg has been used as a natural reservoir for hydroelectric development on the Nelson River through the Lake Winnipeg Regulation project. Manitoba hydro regulates the outflow of the lake to accommodate increased energy demands in the winter. The amount of spring and early summer outflow is reduced in order to increase the amount of outflow available in the fall and winter. To accomplish this Manitoba hydro constructed three channels to increase winter outflow. The Jenpeg Generating Station and Control Structure were also created to harness the energy from the outflow and a dam was built at the outlet of Kiskitto Lake to prevent water backing up into that lake. The natural water level of Lake Winnipeg was between 216.7 and 217.9 meters before the regulation project began. Water levels since the start of the project have been consistently maintained at the natural levels, however, at times of drought or flooding these levels have been changed to maintain necessary outflow levels (Manitoba Hydro online report, 27 January, 2003. <http://www.hydro.mb.ca/issues/lake_wpg_regulation.shtml>). The impact that Lake Winnipeg regulation has had on biodiversity within the lake has not been determined, however, other large-scale hydroelectric development projects have been found to negatively impact biodiversity levels (Rosenberg *et al.* 1997).

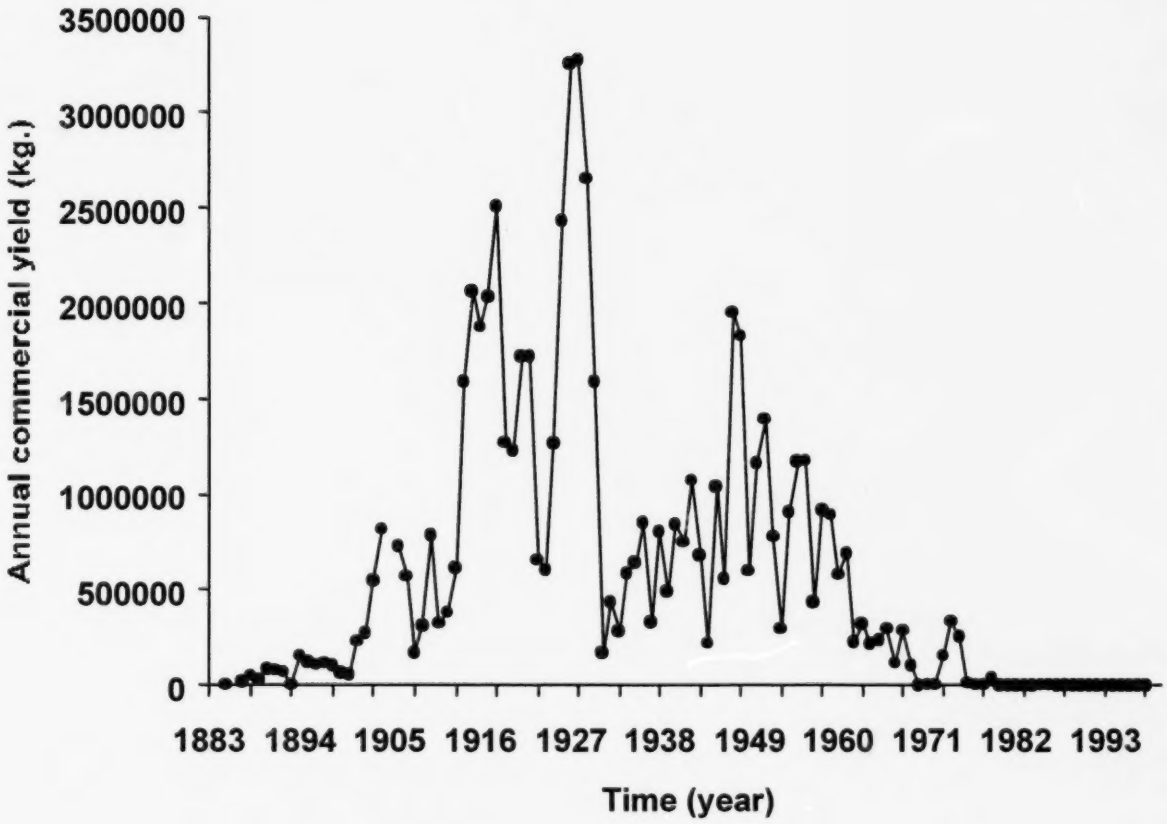

Figure 7. Lake Winnipeg annual cisco production record. Source: Manitoba Conservation, Fisheries Branch.

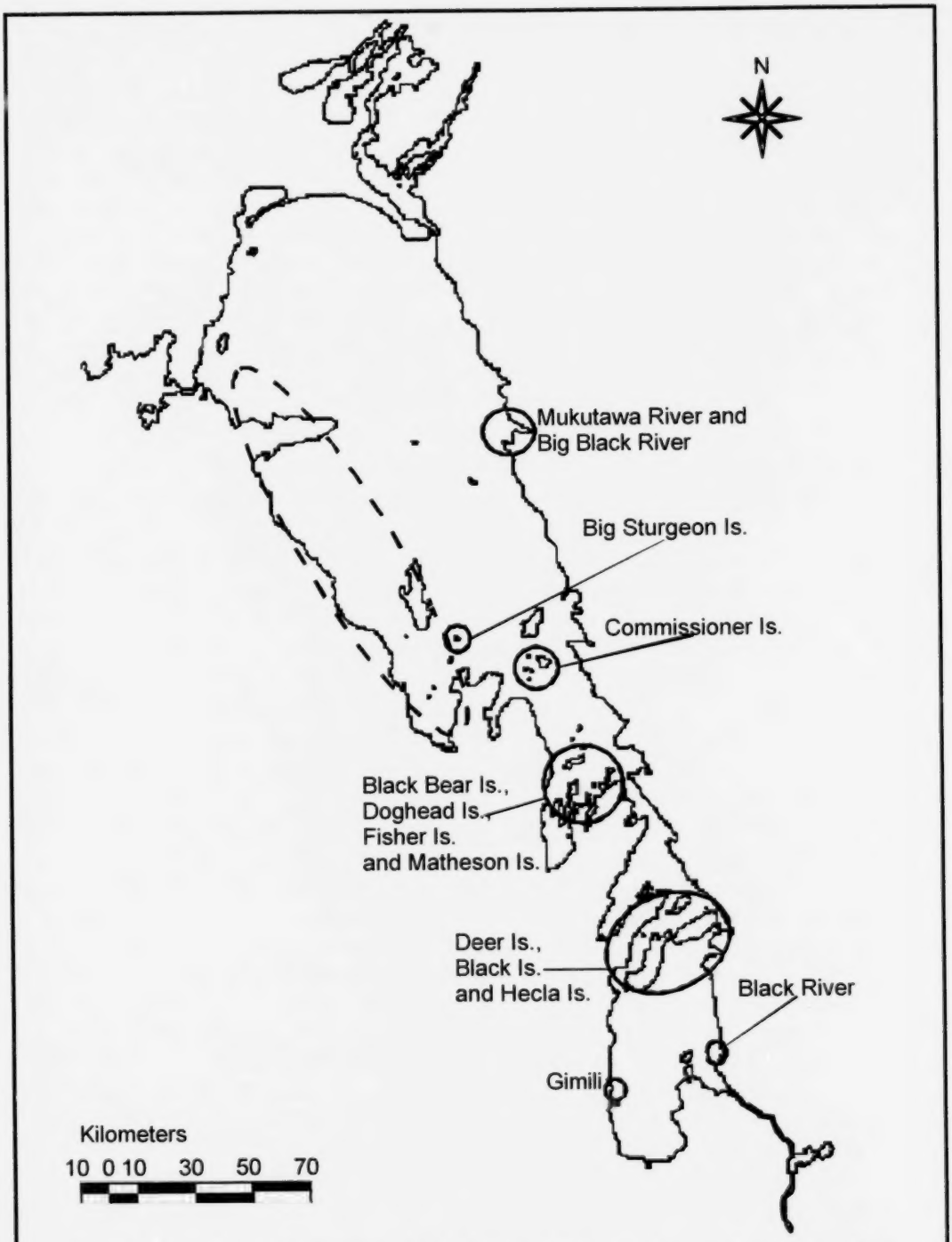

Figure 8. Map of Lake Winnipeg, Manitoba with shortjaw cisco collection locations made by Bajkov (---) and Keleher (—).

STATUS OF SHORTJAW CISCO IN GEORGE LAKE, MANITOBA

EVIDENCE OF SHORTJAW CISCO IN GEORGE LAKE, MANITOBA

Original Description of Shortjaw cisco in George Lake.

Until Clarke's 1973 work the ciscoes found in George Lake were referred to as *C. hoyi*, the bloater, a common species in the Great Lakes (Gibson and Johnson 1969). In Gibson and Johnson's 1969 study five ciscoes were caught at a depth of 107 feet in the upper basin of the lake and another 35 were caught at 80 feet in the mid basin, both using 1.5 inch mesh. No description of the fish was given in the report. The fish were identified as *C. hoyi* based on previous reports done by the province in the 1930's and 40's (J. Beyette, Manitoba Conservation, Lac Du Bonnet, pers. comm. 2001). In Clarke's (1973) study of the Coregonine fishes he collected five specimens from George Lake. The gillraker counts for these specimens ranged from 33 to 37 with a mean of 35.4. Based on the gillraker counts and other shortjaw cisco-like characters, such as short gillraker length, long maxillary length, large eye diameter, and large premaxillary angle, Clarke (1973) considered the George Lake specimens to be synonymous with shortjaw cisco and concluded this to be the only species present in the lake.

The belief that only shortjaw ciscoes were present in the lake was supported by sampling conducted in August 1996 by the author (J.R.), T. Todd, and R. A. Bodaly (Fisheries and Oceans Canada, Winnipeg) who collected only shortjaw cisco. These specimens were identified primarily by low gillraker counts and were noted by T. Todd to be somewhat distinct from Great Lakes shortjaw cisco populations morphologically. They were considered to be similar to a population of putative shortjaw cisco found in White Partridge Lake, Ontario (T. Todd, pers. comm. 2001). The sampling was done in the north basin of the lake, the deepest region. In August 2000 the north basin was sampled by the author (L.M.) and Mike Papst (Fisheries and Oceans Canada, Winnipeg) using 10 to 25 mm mesh nets. Two, 120 meter nets were set at 145 to 148 feet overnight. A total of 70 specimens were collected, all of which were considered to be putative shortjaw ciscoes based on gillraker counts and general morphology. This further supported the belief that only one species of cisco was present in George Lake.

In November 2000 the author (L. M.) was given eleven ciscoes collected from George Lake by Jim Beyette of Manitoba Conservation. The ciscoes were found to have higher gillraker counts than previously found in other specimens collected from the lake, ranging from 38 to 43, suggesting the presence of lake herring. The specimens were collected in 1999 at a depth of 75 feet or less primarily near shore and islands in the north basin of the lake.

In 2001 ciscoes were collected from George Lake by the author (L.M.) and Jim Johnson using 10 to 25 mm and 10 to 60 mm mesh size gill nets set at depths from four to 12 meters. A total of 24 specimens were analyzed and were found to differ from the previously collected cisco specimens in several ways. The 2001 specimens were found to have high total gillraker counts (range of 39 to 44 and a mean of 42), long gillraker lengths, small premaxillary angles (42.6° average), short maxillary lengths, and short snout lengths. The low form collected in 2000 had gillraker counts of 30 to 39 (mean 34), short gillraker

lengths, large premaxillary angles (49.3° average), long maxillary lengths, and long snout lengths. When compared to one another through principal components analysis the two forms were found to be completely separated providing further evidence that they represent two distinct species. Based on these distinguishing characters the low form was identified as putative shortjaw cisco while the high form was identified as lake herring.

Conclusion

Shortjaw ciscoes or a shortjaw cisco-like form is present in the deepest region of George Lake. These specimens show morphological similarities to other putative populations of shortjaw cisco throughout its range such as Lake Athapapuskow, Clearwater Lake, and Reindeer Lake. The lake also contains lake herring in the shallower regions. Hopefully morphological and genetic work can enable us to come to a conclusion about their taxonomic identity.

DISTRIBUTION OF CISCOES IN GEORGE LAKE

Shortjaw ciscoes have been collected only from the deepest region of George Lake in gill nets set at the bottom of the north basin. Manitoba Conservation has no reports of shortjaw ciscoes from shallower waters in the lake but they have collected lake herring from such regions. The mid- and southern basins of the lake are not as deep as the north one but they may also have shortjaw ciscoes present in them. Further sampling throughout the entire lake should answer questions about cisco distribution in George Lake. Figure 9 shows the depth contours of George Lake.

IMPACTS

George Lake is a small somewhat isolated lake in southern Manitoba connected to the Winnipeg River system. Rainbow smelt are a non-native species to Manitoba and have been spreading throughout the province from Ontario. The species has not been found in George Lake but the possibility of the species invading threatens the current ecosystem. Rainbow smelt were partially responsible for the decline of ciscoes in the Great Lakes due to their ability to out-compete ciscoes. If this non-native fish is able to spread into the waters of George Lake then the existence of shortjaw cisco and lake herring in the lake may be at risk. Future study will determine whether rainbow smelt have invaded the lake or not. George Lake and other water bodies potentially threatened by rainbow smelt should be monitored closely. The small size of the lake makes the potential loss of a species through hybridization a possible factor. Putative shortjaw ciscoes are found primarily in the deep basin of the lake, which is not very extensive. If the population of shortjaw cisco in the lake is stable, the actual size of the population is likely small compared to larger water bodies where shortjaw cisco is normally found. The small population size increases the impact that loss of habitat may have on the population as the extent of suitable deep habitat is extremely small. Climate change may contribute to this as one of its impacts has been found to be the loss of cold, deepwater habitat. Although no commercial fisheries exist in the lake it does support a recreational fishery brought in by a local lodge and a few cabins. The recreational fishery is aimed at smallmouth bass, northern pike and lake trout so the impact to cisco is minimal to none.

Figure 9. Bathymetric map of George Lake. Note: *C. zenithicus* collection site indicated by dot.

STATUS OF SHORTJAW CISCO IN SANDYBEACH LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN SANDYBEACH LAKE.

Original description of Shortjaw cisco in Sandybeach Lake

In 1993, Wain reported shortjaw cisco as being present in Sandybeach Lake, ON during his study on the effects of rainbow smelt on fish communities of oligotrophic lakes (Wain 1993). Wain collected 15 putative shortjaw cisco and 264 lake herring in July, 1990. The shortjaw cisco were noted to have atypical morphological characteristics from cisco such as subterminal mouths, larger eye diameters and greater head to body length ratios. The number of gillrakers from the first branchial arch of the shortjaw cisco were found to range from 35 to 40 with a mean of 37.1 while the lake cisco ranged from 39 to 46 with a mean of 41.6 (subsample of 16 individuals). Based on this evidence and descriptions of shortjaw cisco from Scott and Crossman (1973) and Clarke (1973), Wain considered Sandybeach Lake to have a sympatric population of shortjaw cisco coexisting with lake herring. Shortjaw cisco accounted for 8.2% of the total cisco catch in the deep pelagic nets (15 of 182 fish) but because they were identified in the laboratory, further ecological information was not recorded.

Conclusion

Shortjaw cisco or a shortjaw cisco-like form are apparently present in Sandybeach Lake, however, due to the small number that were caught in Wain's (1993) study they are considered to be rare. Shortjaw cisco and lake herring were found to be declining in numbers due to the proliferation of introduced rainbow smelt within the lake. The low relative abundance of new year classes of both cisco species suggest that rainbow smelt are having an adverse effect on cisco populations. This impact has been noted in various other instances where rainbow smelt invaded lakes with cisco being reduced from the most dominant species to rare over a span of a few years (Wain 1993).

DISTRIBUTION OF SHORTJAW CISCO IN SANDYBEACH LAKE

Wain (1993) caught 43 cisco in gill nets set at 35 to 40 meters in mesh sizes ranging from 10 to 38 mm. Some of these cisco may represent shortjaw cisco given their usual preference for deepwater habitats and 41 meters being the maximum depth for Sandybeach Lake (Wain 1993). Sandybeach Lake has approximately 4 km^2 of greater than 40 meter depths in the northeast region of the lake and this is most likely where shortjaw cisco can be found. Figure 10 shows the different depth regions in the lake along with some other useful parameters.

IMPACTS

As mentioned above Sandybeach Lake has been invaded by rainbow smelt in the recent past and this factor may have a dramatic impact on not only shortjaw cisco but the entire fish community of the lake. Wain's (1993) initial findings show declines in both lake herring and shortjaw cisco with little evidence of young-of-the-year. He does suggest that the shortjaw cisco populations may be less susceptible to the impacts of rainbow smelt because of their deepwater habitat preference and their preference for *Pontoporeia affinis*

and *Mysis relicta* instead of micro-crustaceans which are heavily influenced by the smelt. Little is know about the ecology of larval and juvenile shortjaw cisco so despite the fact that rainbow smelt may not directly limit adult shortjaw cisco, they may negatively influence their young and reduce or even extirpate the species over time. Climate change may negatively impact shortjaw ciscoes within Sandybeach Lake as it has been shown to cause a loss of cold, deepwater habitat. Shortjaw cisco are usually found in these deeper waters so a reduction in suitable habitat would likely cause increased competition with sympatric lake herring.

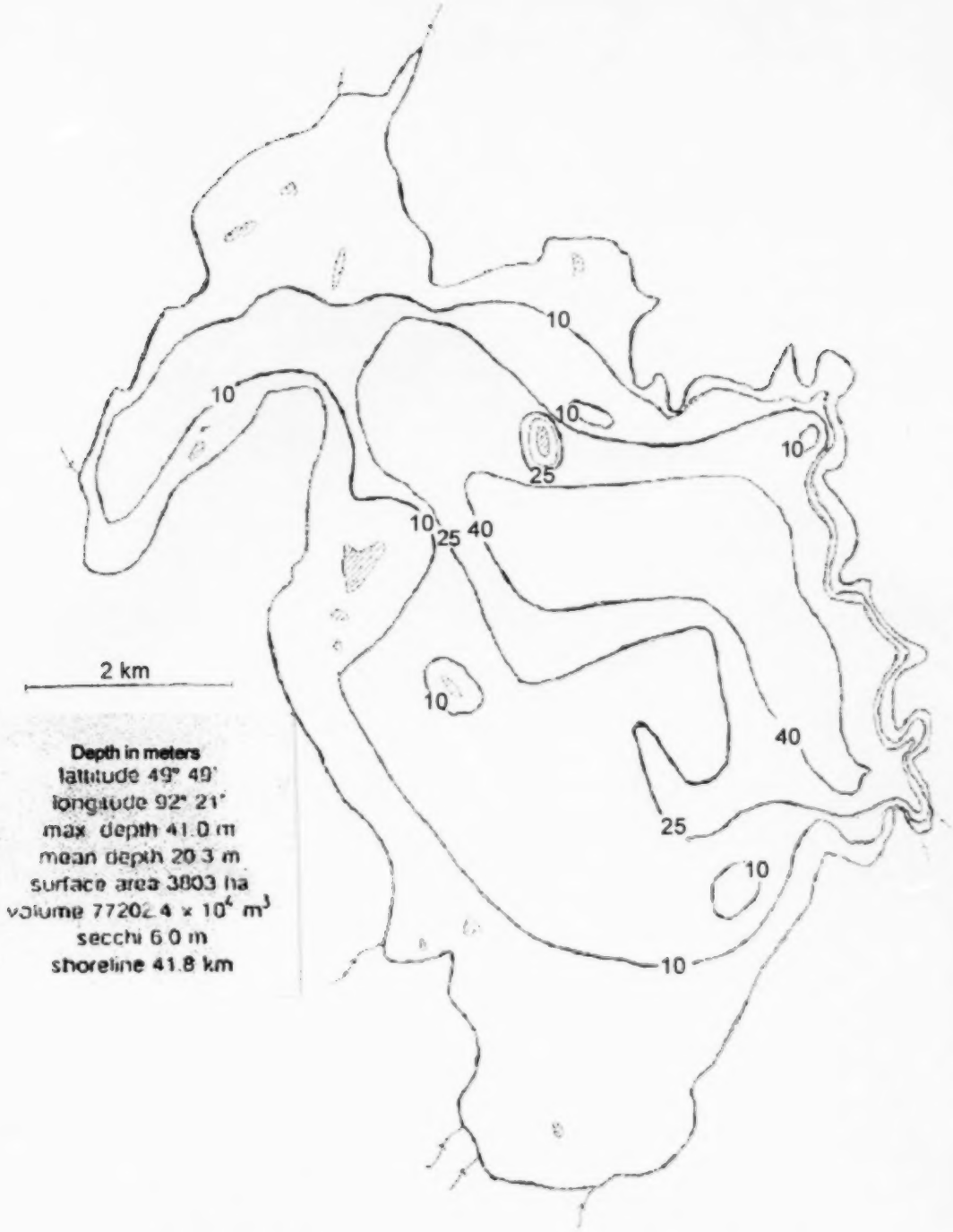

Figure 10. Bathymetric map of Sandybeach Lake (adapted from Wain 1993).

STATUS OF SHORTJAW CISCO IN LAKE OF THE WOODS, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN LAKE OF THE WOODS

Original description of Shortjaw cisco in Lake of the Woods

In 1973 Clarke reported Lake of the Woods as having shortjaw cisco present. Clarke cited Hinks' 1943 Guide to the Freshwater Fishes of Manitoba as the first source of this identification. In his own study, Clarke collected 34 ciscoes from Lake of the Woods, 18 of which were found to have gillraker counts of 30 to 41 and the remaining 16 were found to have gillraker counts ranging from 41 to 51. He referred to the former group as the low group and the latter group as the high group. Principal components analysis successfully separated the two forms when factor 1 and factor 3 were plotted against one another. The characters most responsible for factor 1 were body depth, mandible length, and upper jaw length, all of which were found to be greater in the low group. Factor 3 was considered the gillraker factor because the highest loading characters were upper gillraker count, lower gillraker count, and gillraker length. The low group was found to have lower counts and shorter lengths than the high group. When compared to other low groups from different water bodies such as Lac Seul, Sandy Lake, George Lake, and Reindeer Lake, the Lake of the Woods low group was very similar and was considered by Clarke (1973) to be the *C. zenithicus*.

Conclusion

Based on Clarke's (1973) findings there appears to be a shortjaw cisco-like form in Lake of the Woods. The overall similarity of the specimens to populations of low gillraker groups in other lakes suggests that they represent the same species. The characters distinguishing the low group from the high group are similar to the characters reported for shortjaw cisco (Scott and Crossman 1973).

DISTRIBUTION OF CISCOES IN LAKE OF THE WOODS

Lake of the Woods is located on the border of Manitoba and Ontario with the majority of the water body being found in Ontario and some in northern Minnesota (Figure 1). Little information is available about cisco distributions in Lake of the Woods. Clarke (1973) did not report any collection location information for Lake of the Woods so it is unknown where the low or high groups were found. The lake is large and has a high diversity of habitats, which may enable multiple populations of ciscoes to be present. It is likely that the deepwater putative shortjaw cisco may be present in deep basins throughout the lake, however, further study of this water body is needed to determine if they are indeed present and if so what their distribution may be.

IMPACTS

With the lack of information available about cisco populations in Lake of the Woods it is difficult to know the potential threats that exist. One factor which likely has a negative impact on cisco populations within the lake is the presence of rainbow smelt, the same species which contributed to the demise of many forms of ciscoes in the Great Lakes. Rainbow smelt are non-native to the area and they likely, as in other water bodies, are in

direct competition for resources with cisco populations. Increased resource competition may lead to niche overlap between the deepwater shortjaw cisco and the midwater lake herring. Increased contact between the two species may ultimately have the affect of reducing reproductive isolating mechanisms and result in introgression. Lake of the Woods supports a large recreational fishery, however, ciscoes do not contribute directly to this fishery. Ciscoes represent an important forage fish for larger fish sought after by the recreational fishery. Lake of the Woods has seen increases in development in the area and this has led to eutrophic conditions in some parts of the lake. The full impacts of this are unknown, however, the nutrient amounts entering the lake should be monitored closely to maintain the biodiversity within the lake.

STATUS OF SHORTJAW CISCO IN LAC SEUL, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN LAC SEUL

Original description of Shortjaw cisco in Lac Seul

In 1930 Dymond and Pritchard reported two forms of cisco from Lac Seul, *C. artedi* and *C. nipigon* based on gillraker counts. In 1973 Clarke visited the lake and collected 63 cisco specimens. Of these 39 were found to have gillraker counts ranging from 31 to 37, which Clarke referred to as the low form. The remaining 24 were placed in two groups, one group having 22 specimens ranging from 41 to 48 and the other group having two specimens of 54 and 57. Clarke noted the lower group differed from the two high groups in general appearance by having shorter gillrakers and longer upper jaws. These findings were further supported by principal components analysis. The low group was found to be separate from the high groups when factors 1 and 3 were plotted together. Deeper body, longer mandible, longer upper jaw, fewer and shorter gillrakers were found to be the common characters within the low group and differing from the upper groups. When compared to low forms from other lakes the Lac Seul specimens were found to be very similar and Clarke (1973) considered them to be *C. zenithicus* and not *C. nipigon* as Dymond and Pritchard (1930) had reported.

Conclusion

Based on Clarke's (1973) findings there appears to be a form of shortjaw cisco-like ciscoes present in Lac Seul. The overall similarity of the specimens to populations of low gillraker groups in other lakes suggests that they represent the same species. The characters distinguishing the low groups from the high groups are similar to the characters reported for shortjaw cisco (Scott and Crossman 1973).

DISTRIBUTION OF CISCOES IN LAC SEUL

Lac Seul is located in northwestern Ontario north of the town of Dryden (Figure 1). Little information is available about cisco distributions in Lac Seul. Clarke (1973) did not report any collection location information for Lac Seul so it is unknown where the low or high groups were found. The lake is large and has a high diversity of habitats, which may enable multiple populations of ciscoes to be present. It is likely that putative shortjaw cisco

may be present in deep basins throughout the lake, however, further study of this water body is needed to determine if they are indeed present and if so what their distribution may be.

IMPACTS

With the lack of information available about cisco populations in Lac Seul it is difficult to know the potential threats that exist. Rainbow smelt have been found in Sandybeach Lake (Wain 1993) just south of Lac Seul. Rainbow smelt are non-native to the area and they likely, as in other water bodies, are in direct competition for resources with cisco populations. Increased resource competition may lead to niche overlap between the deepwater shortjaw cisco and the midwater lake herring. Increased contact between the two species may ultimately have the affect of reducing reproductive isolating mechanisms and result in introgression. Climate change may contribute to increased competition and possible introgression as it has been found to cause a reduction in the amount of cold, deepwater habitat where shortjaw ciscoes are commonly found. Lac Seul supports a recreational fishery, however, ciscoes do not contribute directly to this fishery. Ciscoes represent an important forage fish for larger fish sought after by the recreational fishery.

STATUS OF SHORTJAW CISCO IN DEER LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN DEER LAKE

Original description of Shortjaw cisco in Deer Lake

In 1964 Ryder *et al.* reported finding two forms of cisco from Deer Lake, Ontario. They tentatively identified one form as lake herring and the other as *C. nigripinnis* based primarily on gillraker counts. In 1973 Clarke reported finding two specimens with gillraker counts of 35 and two specimens with gillraker counts of 50 and 52. Due to the small sample size obtained Clarke (1973) was unable to include the Deer Lake specimens in his analysis, however, he did note that the low forms had shorter gillrakers and shorter paired fins than the high forms. The large range in gillraker counts between the specimens suggests that multiple forms of cisco exist in Deer Lake. The identification of the lower form as *C. nigripinnis* was considered invalid and Clarke's (1973) concluded that this species was limited to the Great Lakes and Lake Nipigon. Beyond the Great Lakes he recognized only two species, lake herring and shortjaw cisco, with any variation being considered to be multiple forms of lake herring (Clarke 1973).

Conclusion

At the time of Clarke's (1973) study there seemed to be two extant forms of cisco present in Deer Lake, however, few specimens were caught suggesting the populations were small. Approximately 30 years have passed since the lake was last sampled for ciscoes and it is impossible to know what changes may have occurred to these populations.

DISTRIBUTION OF CISCOES IN DEER LAKE

Deer Lake is located in northwestern Ontario in relative isolation (Figure 1). Little information is available about cisco distributions in Deer Lake. Clarke (1973) did not report any collection location information for Deer Lake so it is unknown where the low or high

groups were found. The lake is large and has a high diversity of habitats, which may enable multiple populations of ciscoes to be present. It is possible that putative shortjaw cisco may be present in deep basins throughout the lake, however, further study of this water body is needed to determine if they are indeed present and if so what their distribution may be.

IMPACTS

With the lack of information available about cisco populations in Deer Lake it is difficult to know the potential threats that exist. The relative isolation of the lake greatly diminishes the chances of non-native species introductions and overfishing.

STATUS OF SHORTJAW CISCO IN BIG TROUT LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN BIG TROUT LAKE

Original Description of Shortjaw cisco in Big Trout Lake

In 1964 Ryder *et al.* reported finding two forms of cisco from Big Trout Lake, Ontario. They tentatively identified one form as lake herring and the other as shortjaw cisco based primarily on gillraker counts. In 1973 Clarke reported finding one specimen with a gillraker count of 35 and two specimens with gillraker counts of 40 and 45. Due to the small sample size obtained Clarke (1973) was unable to include the Big Trout Lake specimens into his analysis, however, he did note that the low forms had shorter gillrakers and shorter paired fins than the high forms. The large range in gillraker counts between the specimens suggests that multiple forms of cisco exist in Big Trout Lake.

Conclusion

At the time of Clarke's (1973) study there seemed to be two extant forms of cisco present in Big Trout Lake, however, few specimens were caught suggesting the populations were small. Approximately 30 years have passed since the lake was last sampled for ciscoes and it is impossible to know what changes may have occurred to these populations.

DISTRIBUTION OF CISCOES IN BIG TROUT LAKE

Big Trout Lake is located in northwestern Ontario in relative isolation (Figure 1). Little information is available about cisco distributions in Big Trout Lake. Clarke (1973) did not report any collection location information for Big Trout Lake so it is unknown where the low or high groups were found. The lake is large and has a high diversity of habitats, which may enable multiple populations of ciscoes to be present. It is possible that putative shortjaw cisco may be present in deep basins throughout the lake, however, further study of this water body is needed to determine if they are indeed present and if so what their distribution may be.

IMPACTS

With the lack of information available about cisco populations in Big Trout Lake it is difficult to know the potential threats that exist. The relative isolation of the lake greatly diminishes the chances of non-native species introductions.

STATUS OF SHORTJAW CISCO IN LOONHAUNT LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN LOONHAUNT LAKE

Original description of Shortjaw cisco in Loonhaunt Lake

There is very little information available about any shortjaw cisco populations within Loonhaunt Lake which is located 44 air km northwest of Fort Francis, Ontario. In September of 1985 specimens believed to be shortjaw ciscoes were collected by A. Van Rees and B. Jackson. These specimens are located in the Royal Ontario Museum, however, no other information was available about their identification etc. On June 28th 2001 D. McMahon of the Ministry of Natural Resources, ON, collected more specimens from the same location in Loonhaunt Lake. Information regarding their identification was also unavailable.

Conclusion

Due to the uncertain identification of shortjaw cisco within Loonhaunt Lake, the previously collected specimens should be examined and the results added to the current extent of shortjaw cisco literature.

DISTRIBUTION OF CISCOES IN LOONHAUNT LAKE

No information available.

IMPACTS

No information available.

STATUS OF SHORTJAW CISCO IN TROUT LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN TROUT LAKE

Original description of Shortjaw cisco in Trout Lake

The only report of shortjaw cisco from Trout Lake comes from specimens in the Royal Ontario Museum's collection. These specimens were reported by Clarke in 1973 but he did not report any information about who collected them and when. Clarke did not include Trout Lake in his analysis.

Conclusion

The lack of information about museum specimens shows a need for both finding the original specimens and analyzing them to confirm their identification and also for sampling new specimens from the lake.

DISTRIBUTION OF CISCOES IN TROUT LAKE

No information available.

IMPACTS

No information available.

STATUS OF SHORTJAW CISCO IN BASSWOOD LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN BASSWOOD LAKE

Original Description of Shortjaw cisco in Basswood Lake

The only information for putative shortjaw ciscoes from Basswood Lake was in Steinhilber 2000. The specimens examined were obtained through the Royal Ontario Museum, however, no information was available about who collected them and when they were collected (M. Steinhilber, pers. comm. 2002). Steinhilber obtained 10 specimens through the museum and found they had gillraker counts ranging from 30 to 37 with a mean of 32. He also noted that they had fewer and shorter gillrakers along with larger eyes when compared to putative shortjaw cisco specimens from other locations (Steinhilber 2000). Principal components analysis showed the Basswood Lake specimens to be similar to specimens from Lake Nipigon and George Lake due to gillraker length and dorsal fin base length.

Conclusion

The results of Steinhilber's (2000) work suggest the existence of a low gillraker shortjaw cisco-like form in Basswood Lake. The lack of information about who collected them and when they were collected needs to be determined and further sampling is needed to verify the reports.

DISTRIBUTION OF CISCOES IN BASSWOOD LAKE

No information available.

IMPACTS

No information available.

STATUS OF SHORTJAW CISCO IN WHITE PARTRIDGE LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN WHITE PARTRIDGE LAKE

Original description of Shortjaw cisco in White Partridge Lake

The only report of putative shortjaw ciscoes from White Partridge Lake comes from specimens in the Royal Ontario Museum's collection. These specimens were reported by Clarke in 1973 but he was unable to obtain any information about who collected them and when. Clarke did not include White Partridge Lake in his study so no further information is available. Specimens have been collected from White Partridge Lake recently and have morphologically been found to be similar to putative shortjaw cisco specimens collected from George Lake, Manitoba and other inland populations of shortjaw cisco-like forms. The

total gillraker counts for these specimens were less than 38 and they seemed to be spring spawners (T. Todd, pers. comm. 2002). Based on spring spawning and their isolated distribution it is possible that they evolved independently from lake herring since colonizing the lake 10,000 years ago and mtDNA analysis by Julie Turgeon (Department of Biology, University of Laval, QC) could not distinguish them from Lake Nipigon lake herring (Nick Mandrak, Fisheries and Oceans Canada, Burlington, pers. comm. 2002).

Conclusion

The lack of information about specimens for this lake shows a need for further analysis to confirm their identification. A shortjaw cisco-like form is present in the lake but further work is necessary to determine if it is indeed shortjaw cisco and not a low gillrakered form of lake herring.

DISTRIBUTION OF CISCOES IN WHITE PARTRIDGE LAKE

No information available.

IMPACTS

No information available.

STATUS OF SHORTJAW CISCO IN SANDY LAKE, ONTARIO

EVIDENCE OF SHORTJAW CISCO IN SANDY LAKE

Original description of Shortjaw cisco in Sandy Lake

The original occurrence of ciscoes in Sandy Lake was made based on specimens from the Royal Ontario Museum. Sandy Lake was listed as having two species present, *C. artedi* and *C. hoyi*. In 1973 Clarke collected ten cisco specimens from Sandy Lake, Ontario. Of these, seven were found to have gillraker counts from 37 to 43 and three were found to have counts from 51 to 54. Despite the higher than usual gillraker counts Clarke (1973) considered the seven low-rakered forms to possibly be shortjaw cisco. Principal component analysis found them to be similar to low forms from other lakes supporting his original identificatio n. Some differences were noted between the Sandy Lake forms and the others including slimmer body profile, longer snouts, and longer paired fins (Clarke 1973). In 2000 Steinhilber looked at seven specimens of putative shortjaw cisco from Sandy Lake and found them to have gillraker counts ranging from 42 to 44. He also found these specimens to have longer gillrakers and longer upper jaws than populations of putative shortjaw cisco from other lakes. Principal component analysis found these differences to not be enough to separate the Sandy Lake specimens from other shortjaw cisco populations supporting Clarke's (1973) identification (Steinhilber 2000).

Conclusion

Despite the small sample size and the higher than normal gillraker counts the specimens collected from Sandy Lake by Clarke (1973) support the presence of a shortjaw cisco-like form within the lake. Further sampling of the lake would confirm this identification and increase our knowledge of their status in the lake.

DISTRIBUTION OF CISCOES IN SANDY LAKE

Sandy Lake is located in northwestern Ontario and is relatively isolated (Figure 1). No information is available about where the cisco specimens were collected from Sandy Lake.

IMPACTS

With the lack of information available about cisco populations in Sandy Lake it is difficult to know the potential threats that exist. The relative isolation of the lake greatly diminishes the chances of non-native species introductions.

SUMMARY OF THREATS TO PUTATIVE SHORTJAW CISCO POPULATIONS

None of the populations of putative shortjaw cisco outside the Great Lakes are directly exploited through commercial fisheries. Where commercial fisheries do occur they likely have little impact on shortjaw cisco populations as by-catch because of the large mesh size used. The indirect impacts that may occur from the removal of either cisco predators (lake trout) or competitors (lake whitefish) through commercial fisheries is unknown. Domestic use of ciscoes throughout their range is likely limited to bait for lake trout and some smoking for food. Habitat degradation in inland lakes with populations of putative shortjaw cisco is likely low, however, the effects of climate change on some of the northern populations may be higher. Exotic species pose a threat to some populations especially those within or near the expanding range of rainbow smelt. Table 2 summarizes the amount of threat each of the above has on reported shortjaw cisco populations.

VALIDITY OF SHORTJAW CISCO IDENTIFICATIONS

The validity of putative shortjaw cisco identifications from each water body have been summarized in Table 1. These views represent those of the authors based on the current state of knowledge found within the literature. For several lakes the identification of a shortjaw cisco-like form has been supported through morphological studies and their identification has been generally accepted as valid. Other lakes listed as uncertain have received some attention, however, the evidence supporting the occurrence of putative shortjaw ciscoes is either not enough or outdated.

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Table 2. Threats to populations of putative *Coregonus zenithicus in* western Canada.

	Targetted Exploitation	By-catch Exploitation	Domestic Exploitation	Habitat Degradation	Climate Change	Exotic Species
Great Slave Lake	no	medium to low	low	low	medium	low
Lake Athabasca	no	low	low	low	medium	low
Barrow Lake	no	not relevant	none	low	medium	low
Reindeer Lake	no	low	low	low	medium	low
Lake Athapapuskow	no	not relevant	none	low	medium	low
Clearwater Lake	no	not relevant	none	low	medium	low
Lake Winnipeg	no	medium to low	low	medium to high	medium	high
George Lake	no	not relevant	none	low	low	medium
Lake of the Woods	no	not relevant	none	low to medium	low	medium
Sandybeach Lake	no	not relevant	unknown	low	low	high
Lac Seul	no	not relevant	unknown	low	low	high
Deer Lake	no	not relevant	unknown	low	low	low
Big Trout Lake	no	not relevant	unknown	low	low	low
Trout Lake	no	not relevant	unknown	low	low	low
Basswood Lake	no	not relevant	unknown	low	low	medium
Sandy Lake	no	not relevant	unknown	low	low	low
White Partridge Lake	no	not relevant	unknown	low	low	low
Loonhaunt Lake	no	not relevant	unknown	low	low	medium

REFERENCE LIST

Bailey, R.M. and G.S. Smith. 1981. Origin and geography of the fish fauna of the Laurentian Great Lakes basin. Can. J. Fish. Aquat. Sci. 38: 1539-1561.

Bajkov, A. 1930. Fishing industry and fisheries investigations in the prairie province. Trans. Am. Fish. Soc. 60: 215-237.

Bajkov, A. 1932. The genus *Leucichthys* (ciscoes or tullibees) in Manitoban waters. Contrib. Can. Biol. Fish. 7(26): 325-333.

Bernatchez, L., F. Colombani, and J.J. Dodson. 1991. Phylogenetic relationships among the subfamily Coregoninae as revealed by mitochondrial DNA restriction analysis. J. Fish. Biol. 39: 283-290.

Bodaly, R.A., J. Vuorinen, R.D. Ward, M. Luczynski, and J.D. Reist. 1991. Genetic comparisons of New and Old World coregonid fishes. J. Fish. Biol. 38: 37-51.

Clarke, R.M. 1970. The taxonomy of three sympatric species of ciscoes in northern Manitoba. M.Sc. Thesis. University of Manitoba, Winnipeg. 77 pp.

Clarke, R.M. 1973. The systematics of ciscoes (Coregonidae) in central Canada. Ph.D. Thesis, University of Manitoba, Winnipeg. 243 pp.

Day, A.C. 1983. Biological and population characteristics of, and interactions between an unexploited burbot (*Lota lota*) population and an exploited lake trout (*Salvelinus namaycush*) population from Lake Athapapuskow, Manitoba. M. Sc. Thesis, University of Manitoba, Winnipeg. 177 pp.

Dymond, J.R. 1926. The fishes of Lake Nipigon. Pub. Ont. Fish. Res. Lab. no. 27.

Dymond, J.R. 1943. The coregonine fishes of northwestern Canada. Contrib. Roy. Ont. Mus. Zool. no. 24.

Dymond, J.R. and A. L. Pritchard. 1930. Some ciscoes or lake herrings of western Canada. Contrib. Can. Biol. Fish. 5: 469-474.

Gibson, R.J., and L.J. Johnson. 1969. A Limnological investigation of George Lake (Whiteshell Provincial Park) in 1967. Manitoba Dept. Mines Natur. Res. Fish. Br. MS Rep. 69-3. 48 pp.

Keleher, J.J. 1948. Observations on northern Lake Winnipeg tullibee during the summer 1947. Unpublished Report. Manitoba Dept. Mines Natur. Res.

Keleher, J.J. 1950. Growth, maturity, and Triaenophorus parasitism in relation to taxonomy of Lake Winnipeg ciscoes (*Leucichthys*). Fish. Res. Board Can. Man. Rep. Biol. Stat. No. 509. 74 pp.

Keleher, J.J. 1951. Some meristic characters of some Lake Winnipeg ciscoes (*Leucichthys spp.*). Fish. Res. Board Can. Man. Rep. Biol. Stat. no. 481. 5 pp.

Keleher, J.J. 1972. Supplementary information regarding exploitation of Great Slave Lake salmonid community. Fish. Res. Board Can. Tec. Rep. no. 298. 31 pp.

Koelz, W. 1929. Coregonid fishes of the Great Lakes. Bull. U. S. Bur. Fish. 43: 297-643, 1927.

Harper, G. and J.T. Nichols. 1919. Six new fishes from northwestern Canada. Bull. Am. Mus. Nat. His. Vol. XLI: 263-271.

Hinks, D. 1943. The fishes of Manitoba. Manitoba Dept. Mines and Natur. Res., Winnipeg. 102 pp.

Houston, J.J. 1988. Status of the Shortjaw Cisco, *Coregonus zenithicus*, in Canada. Can. Field Nat. 102: 97-102.

Hubbs, C.L. and K.F. Lagler. 1964. Fishes of the Great Lakes Region. The University of Michigan Press, Ann Arbor. 213 pp.

Lindsey, C.C. 1981. Stocks are chameleons: plasticity in gill rakers of coregonid fishes. Can. J. Fish. Aquat. Sci. 38: 1497-1506.

Lindsey, C.C. and J.D. McPhail. 1986. Zoogeography of fishes of the Yukon and Mackenzie Basins. Pp. 639-674 In: The Zoogeography of North American Freshwater Fishes (C. H. Hocutt and E. O. Wiley, eds.). John Wiley and Sons, New York.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Re. Bd. Can., Bulletin 173, Ottawa.

Ono, R.D., J.D. Williams, and A. Wagner. 1983. Vanishing fish of North America. Stone Wall Press, Washington, DC. 257 pp.

Paterson, C.G. 1969. Occurrence of *Coregonus artedii* and *C. zenithicus* in Barrow Lake, Alberta. J. Fish. Res. Bd. Can. 26(7): 1934-1938.

Rawson, D.S. 1947. Great Slave Lake and Lake Athabasca. In: Northwest Canadian fish surveys in 1944-45. Bull. Fish. Res. Bd. Canada. 72: 45-94.

Rawson, D.S. 1951. Studies of the fish of Great Slave Lake. J. Fish. Res. Bd. Can. 8(4): 207-240.

Reed, K.M., M.O. Dorschner, T.N. Todd, and R.B. Phillips. 1998. Sequence analysis of the mitochondrial DNA control region of ciscoes (genus *Coregonus*): taxonomic implications for the Great Lakes species flock. Mol. Ecol. 7: 1091-1096.

Reist, J.D. 2000. Climate change issues for northern aquatic ecosystems. Dept. Fish. Oceans Climate Variability and Change Impacts, Workshop Proceedings. 4 pp.

Reist, J.D., L.D. Maiers, R.A. Bodaly, J.A. Vuorinen, and T.J. Carmichael. 1998. The phylogeny of new- and old-world coregoninae fishes as revealed by sequence variation in a portion of the d-loop of mitochondrial DNA. - In: R. Eckman, A. Appenzeller, and R. Rosch (eds.): Biology and management of Coregonid Fishes – 1996. Arch. Hydrobiol. Spec. Issues Advanc. Limnol. 50: 323-339.

Remnant, R.A. 1991. An assessment of the potential impact of the rainbow smelt on the fishery resources of Lake Winnipeg. M.N.R.M. Practicum, Natural Resources Institute, University of Manitoba. 170 pp.

Rempel, L.L. and D.G. Smith. 1998. Postglacial fish dispersal from the Mississippi refuge to the Mackenzie River basin. Can. J. Fish. Aquat. Sci. 55: 893-899.

Roberge, M.M., G.Low, and C.J. Read. 1985. Data from an experimental gillnetting program on Great Slave Lake, Northwest Territories, 1980-1981. Can. Data Rep. Fish. Aqu. Sci. No. 537.

Robinson, B.W. and K.J. Parsons. 2002. Changing times, spaces, and faces: tests and implications of adaptive morphological plasticity in the fishes of northern postglacial lakes. Can. J. Fish. Aquat. Sci. 59: 1819-1833.

Rosenberg, D.M., F. Berkes, R.A. Bodaly, R.E. Hecky, C.A., Kelly, and J.W.M. Rudd. 1997. Large-scale impacts of hydroelectric development. Environ. Rev. 5: 27-54.

Ryder, R.A., W.B. Scott, and E.J. Crossman. 1964. Fishes of northern Ontario, north of the Albany River. Roy. Ontario Mus. Life Sci. Contrib. 60: 1-30.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can., Bulletin 184, Ottawa.

Smith, G.R. and T.N. Todd. 1984. Evolution of species flocks of fishes in north temperate lakes. Pp. 45-68 In: Evolution of fish species flocks (A. A. Echelle and I. Kornfield, eds.). University of Maine at Orono Press, Orono.

Smith, G.R. and T.N. Todd. 1992. Morphological cladistic study of coregoninae fishes. Pol. Arch. Hydrobiol. 39: 479-490.

Smith, S.H. 1964. Status of the deepwater cisco population of Lake Michigan. Trans. Am. Fish. Soc. 93(2): 155-163.

Steinhilber, M. 2000. A re-examination of the putative shortjaw cisco (*Coregonus zenithicus*) in Barrow Lake, Alberta and taxonomic evaluation of neighboring cisco populations. M.Sc. Thesis, University of Alberta, Edmonton. 174 pp.

Steinhilber, M. and L. Rhude. 2001. Distribution and relative abundance of the shortjaw cisco (*Coregonus zenithicus*) in Alberta. Alberta Species at Risk Report No. 3. 19 pp.

Steinhilber, M., J.S. Nelson, and J.D. Reist. 2002. A morphological and genetic re-examination of sympatric shortjaw cisco (*Coregonus zenithicus*) and lake herring (*C. artedi*) in Barrow Lake, Alberta, Canada. Biology and Management of Coregonid Fishes.- Arch. Hydrobiol. Spec. Issues Advanc. Limnol. 57: 463-478.

Teller, J.T. 1987. Proglacial lakes and the southern margin of the Laurentide Ice Sheet. Pp. 39-69 *in*: The Geology of North America: North American and Adjacent Oceans During the Last Deglaciation (W. F. Ruddiman and H. E. Wright Jr., eds.). Geological Society of America, Boulder, Colorado.

Todd, T.N. and G.R. Smith. 1980. Differentiation in *Coregonus zenithicus* in Lake Superior. Can. J. Fish. Aquat. Sci. 37: 2228-2235.

Todd, T.N. and G.R. Smith. 1992. A review of differentiation in Great Lakes ciscoes. - .In T.N. Todd and M. Luczynski (eds.) – Biology and Management of Coregonid Fishes. Polskie Archiwum Hydrobiologii 39(3,4): 261-267.

Todd, T.N. and R.M. Stedman. 1989. Hybridization of ciscoes (*Coregonus* spp.) in Lake Huron. Can. J. Zool. 67:1679-1685.

Todd, T.N. and M. Steinhilber. 2002. Diversity in shortjaw ciscoes (*Coregonus zenithicus*) in North America. Arch. Hydrobiol. Spec. Issues Advanc. Limnol. 57: 517-525.

Todd, T.N., G.R. Smith., and L.E. Cable. 1981. Environmental and genetic contributions to morphological differentiation in ciscoes (Coregoninae) of the Great Lakes. Can. J. Fish. Aquat. Sci. 38: 59-67.

Turgeon, J., A. Estoup, and L. Bernatchez. 1999. Species flocks in the North American Great Lakes: molecular ecology of Lake Nipigon ciscoes (Teleostei: Coregonidae: *Coregonus*). Evolution 53(6): 1857-1871.

Turgeon, J. and L. Bernatchez. 2002. Reticulate evolution and phenotypic diversity in North American ciscoes, *Coregonus ssp.* (Teleostei: Salmonidae): implications for the conservation of an evolutionary legacy. Conservation Genetics. In Press.

Wain, D.B. 1993. The effects of introduced smelt (*Osmerus mordax*) on the indigenous pelagic fish community of an oligotrophic lake. M.Sc. Thesis, University of Manitoba, Winnipeg. 131 pp.